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Chemical Soil Solidification and Chemical Sealing of Leaking Concrete

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A contribution to the Journal

DIFFICULT problems in safeguarding special foundation work, cellular cofferdams and shaft construction through quicksand layers led the author in 1936 to investigate, test and actually carry out chemical soil solidification work and internal sealing of cracked, honeycombed and leaking concrete structures. This work was based on the Joosten process, invented in 1925 by a prominent Dutch mining engineer, Dr. Hugo Joosten.

The underlying principles of chemical soil solidification and of chemical sealing of leaking concrete, together with many uses of the processes in water works and other public utilities construction, are here briefly outlined.

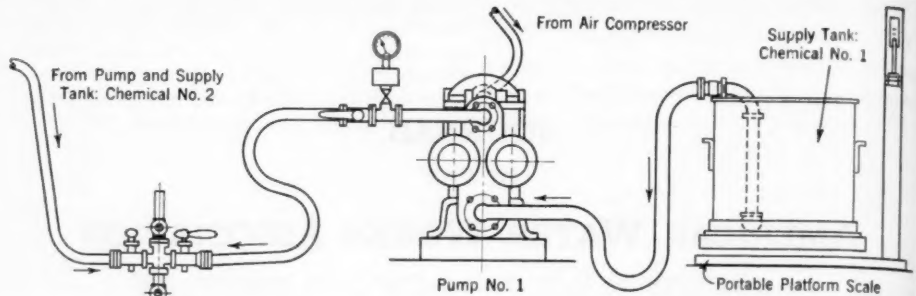
Chemical Soil Solidification

Characteristics

The immediate solidification (sometimes called petrification) of loose siliceous deposits and similar porous material takes place after the consecutive injection of two true solutions through suitably spaced pipes driven into the ground (Fig. 1).

The first chemical consists mainly of a commercial brand of silicate of soda (water glass) to which have been added small amounts of certain metallic salts to retard the rapid gel-forming reaction which occurs when it is brought in contact with gases or with the second chemical, a solution of strong calcium chloride. The resulting gel fills the voids in the soil and binds the grain particles together into a solid, permanent, sandstone-like mass of a hardness which increases with age. This mass is insoluble in water.

Usually laboratory tests are sufficient to determine whether or not the soil in question can be solidified with an assurance of good success. Incor-



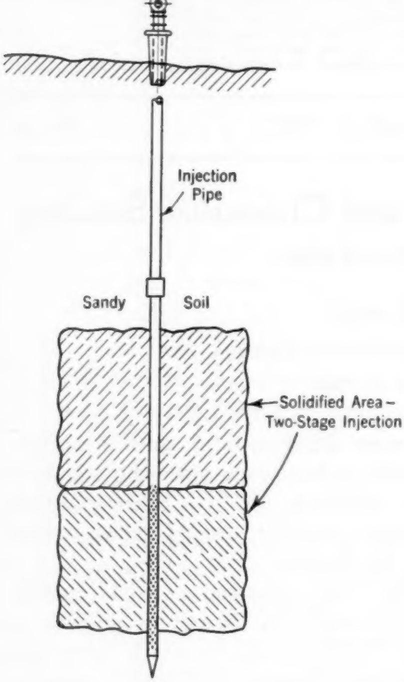


FIG. 1. Schematic Hookup of Injection Equipment—Joosten Process of Chemical Soil Solidification

rect mixtures injected through improper equipment or by a wrong injection plan will lead to disappointment.

The hardness and water-repellent quality of the solidified soil, no matter whether below or above ground water level, depend on the content of silica and quartz in the sandy soil and on the presence or absence of partially decomposed minerals, clay and organic matter. Sharpness of sand is desirable, but sand with rounded grains seems to pack better, giving a denser, solidified mass. Generally speaking, material suitable for chemical treatment is any loose, not too fine, sandy soil; U.S. No. 120-sieve size is about the practical limit. Depths of layers to be treated should not be greater than 60 to 70 ft.

Careful preliminary laboratory tests, a well worked out injection plan and constant watchfulness by the resident engineer and foreman will produce good solidification results even with poor natural layers or layers with unwelcome variations in their character. Solidified material is very similar to a soft to medium-soft natural sandstone. The binding gel hardened within the voids of the untreated sand, being noncrystalline, permits rough dressing or shaping of a surface. For instance, it facilitates the preparation of heavy pipe supports in deep trenches where unstable layers of sand are encountered.

Tests made in the author's laboratory on samples of Chicago sands, of sands from the Atlantic and Pacific Coasts, of Mississippi River sand, and of sand from the Everglades in southern Florida show that the average compressive strength varies from 450 psi. (32.4 tons per sq.ft.) to 875 psi.

(63 tons per sq.ft.). John Mowlem & Company, London engineers and constructors who are using the process widely in subway and large sewer work, obtained tensile stresses of 157 psi. by subjecting to tension tests a 3-ft. piece of 6 in. × 4 in. solidified Thames ballast on supports 18 in. apart, with a center load of 840 lb.

Equipment

(1) Injection pipes similar to well-points, standard size and length according to job conditions.

(2) Compressed air hammer, drop hammer, hydraulic jack or pipe pushers for driving in the injection pipes. Special driving heads and pipe connections have been designed to withstand great punishment when driving through very packed soil or withdrawing from the solidified area at great depths.

(3) Standard double-acting chemical pumps, driven by compressed air with pressures up to 400 psi.

(4) Pressure hose with attachments of a type which will permit quick disconnection.

(5) Suction tanks and containers.

(6) Paddle-type mixing outfit for mixing Chemical No. 2 at the site.

(7) Portable sectional scaffolding tower for use when driving long pipes. This should be of tubular construction which is easily moved from one position to another.

(8) Miscellaneous pipefitter's tools.

(9) Heavy special twin-hydraulic jacks for withdrawal of pipes from injection area.

(10) Compressed air at 100 psi.

Supervision and Labor

As in any construction job, only careful planning and experienced supervision can bring satisfactory results. A Joosten engineer must be capable of interpreting subterranean conditions and should know the limitations of the process to avoid failures.

A crew of one experienced foreman and four laborers is usually sufficient to handle one set of injection equipment. In such a group, two men handle the injection equipment; one man cleans and wire-brushes the withdrawn injectors for immediate re-use; one handy man fills the suction cans or tanks and takes care of the Chemical No. 2 mixing plant. Large solidification contracts are subdivided into suitable sections, each to be handled by a unit crew with one injection set. This arrangement is more economical inasmuch as one compressor plant and one Chemical No. 2 mixing plant will serve three or more injection crews. While the foreman should be thoroughly familiar with the chemical injection equipment, the workmen can be hired locally.

Cost of Solidified Material

Unlike the case of reinforced concrete, which is prepared by using well-known ingredients so that the cost may be estimated within rather close ranges, the cost of solidified soil, which involves indeterminate factors underground, can at present be accurately estimated only after extensive studies of geological and hydrological conditions and other factors governed by local conditions. It can be said, however, that, with the accumulation of experience, the unit cost has been brought down with every job carried out. Although each job presents a different ground water movement pattern, and a new set of conditions governing depth of injection, the cost of 1 cu.yd. of solidified soil in moderate

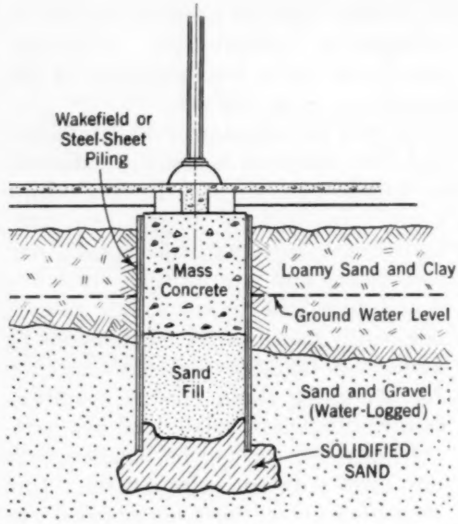


FIG. 2. Chemical Solidification to Spread Bearing Area Under Caissons or Cofferdams and to Seal Bottom of Them

depth below grade will rarely exceed that of good concrete. This might seem high were it not that there is no excavation cost involved. If the solidification is carried on in order to support or strengthen existing foundations, operations in the buildings resting on them in most cases need not be interrupted. Furthermore, chemical soil solidification is often used as a last resort; for instance, when unexpected quicksand cave-ins have occurred and the safety of the whole structure is involved. In such cases, the contractor is willing to pay a heavy price to ward off disaster.

Adaptations

The engineer engaged in the design, construction and maintenance of water works and related public underground structures, including tunnels, shafts, intakes, cofferdams and underpinning work, does not need much imagination to realize the usefulness of the process in this wide field.

Tunneling

For the protection of tunnels under construction, unstable sandy layers are quickly solidified at the tunnel head, in advance of mining. Similarly, the process is applicable, provided the soil is sandy, to tunnels under busy boulevards or streets where the open-cut method is undesirable because it would interrupt traffic. In this case, the injection pipes are driven in horizontally, about parallel to the center line of the large water main, sewer or tunnel, starting from an excavated pit at the sidewalk. The underside of the solidified arch can be dressed or trimmed to receive the cast-iron or concrete pipe section, after excavation of the loose soil underneath. In some cases below ground water level it will be more practical to use telescopic steel rings of 5-ft. lengths to accomplish temporary tunnel connections.

Intakes and Piers

At lake or river intakes to be built within temporary cofferdams, near shore or in greater water depths, the bottom around the driven-in steel-sheet piling can be solidified before or after dewatering in preparation for the concrete foundation. Solidified material binds as strongly to steel anchor rods and steel-sheet piling as reinforcing bars bind to concrete (Fig. 2). Since there is also strong "welding action" to natural rock, a cushion of solidified sand at the bottom or along steel-sheet piling driven to rock gives a strong and tight seal for circular cell or plain straight cofferdams, protecting intakes or forebays of shore water works and filter plants, or cofferdams around

building pits. During construction continuous pumping usually is eliminated or is at least reduced considerably. Sprung-out interlocks or ripped-open sheet pilings are sealed rapidly and economically by solidifying the area outside the dewatered pit around the damaged sheet piles.

Underpinning Without Excavation

To stop dangerous settlement of building walls, column footings, piers or heavy machine foundations or to increase existing foundations so that they will be capable of carrying added loads (Fig. 3), or to prevent disturbance of existing foundations while tunnel mining or deep excavations are going on in adjoining lots or narrow streets (Fig. 4), chemical solidification is undoubtedly the economical solution, provided the material is suitable for treatment. Where bearing ground or rock is too deep to be reached by timber or concrete pile foundations, a mat of solidified soil will provide a support for the pile tips, sufficient in connection with the carrying power obtained by friction to sustain the required superimposed loads plus the necessary factor of safety. Very careful studies of the local geological conditions have to be made in advance to determine the thickness of the solidified soil mat.

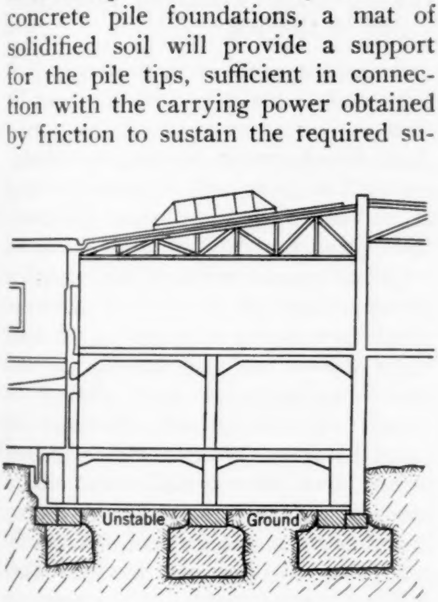
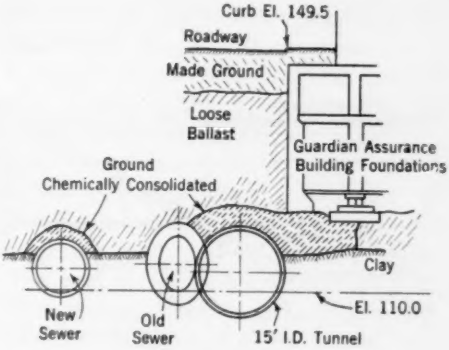


FIG. 3. Chemical Solidification Under Column Footings in Lieu of Piling



From The Engineer, *Nov. 3, 1933 (London)*

FIG. 4. Section Showing Chemical Process as Applied to 26-ft. Tunnel at Monument Station, London

Protection of Ground Water Supplies

The process has also been found very useful in irrigation and flood control, and could be utilized to great advantage in stopping or limiting leakages at large natural water reservoirs by providing subterranean aprons to the rock base of solidified soil within hydraulically-filled earth dams. It may also be used for solidifying pervious strata under such dams between impervious layers of clay or rock which otherwise could not be reached (Fig. 5).

Another field where chemical consolidation will, no doubt, be considered is in the protection of ground water supplies, particularly in Florida, where the expansion of existing supplies and the development of new supplies are planned to supplement the ever-increasing needs of cities, agriculture and industries and also where the danger

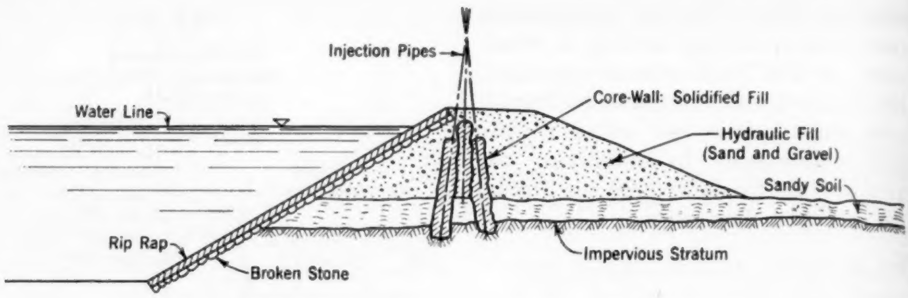


FIG. 5. Earth Dam of a Sedimentation Basin or Reservoir

of salt water encroachment through the aquifer exists. Similar permanent protective work could be achieved in the menaced Ohio River Valley watershed, called by the U.S. Public Health Service and the U.S. Bureau of Mines the "acid zone." In West Virginia alone, for example, it was estimated that, in 1934, 3,500,000 lb. of acids were flowing into the streams from active and abandoned mines, with only 22 per cent of the inactive mines sealed. While there is a possibility that water-bearing natural layers can be sealed by aprons of solidified soil, it is obvious that the source of the concentrated acids must be cut off directly in the abandoned mines. It is possible to do this by injecting the Joosten chemicals under high pressure into the leaks and cracks of the bulkheads. This effective, permanent and economical method is described in detail in the section entitled "Chemical Sealing of Leaking Concrete Structures."

Various Other Applications

While this article is too limited to go into detail, other applications should be mentioned, such as: sinking of shafts or mining through unstable ground or quicksand; providing supports for large water mains if quicksand is encountered in deep trenches; stopping the escape of air at the heading when mining under compressed air (30-psi. pressure) in large tunnel construction (Fig. 6). Often in such cases, air leakage is considerable and free air at the rate of 50,000 cfm. and more has to be supplied. Another application is the protection of existing nearby buildings during construction of tunnels or shafts in narrow city streets (Fig. 7).

The First Large Subsoil Consolidation in the U.S.

A striking example of this work is a large-scale foundation improvement to stop settlement of an 80-ft. long machine foundation under heavily vibrating mill engines and crushers at the main plant of the U.S. Sugar Corporation, Clewiston, Fla. Figure 8 shows a typical cross-section of the existing concrete foundation, 10 ft. 8 in. deep, which had settled unevenly at various spots thereby causing damage to the machinery—a mishap particularly serious in wartime. About 660 cu.yd. of natural sandy layers below ground water level were transformed into a mass of synthetic sandstone with an initial bearing capacity of about 550 psi. (about 40 tons per sq.ft.). This verified the facts obtained in previous laboratory tests. The injection of the chemicals was carried on from out-

side the building, as seen in Fig. 8. Because a service building was located about 24 ft. away, a shallow working pit was necessary to allow the driving of almost horizontal pipes to reach the area directly under the bottom of the foundation, and to clear column footings in front of it. To insure the uniform solidification of the contract area,

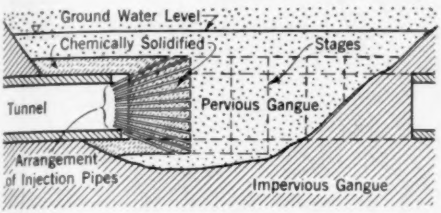


FIG. 6. Chemical Solidification of a Tunnel Head

injection work strictly adhered to a carefully laid out plan prepared by the author and adjusted to local conditions in close co-operation with Moran, Proctor, Freeman & Mueser, New York, the consulting engineers retained by the owners for the entire improvement project.

Twenty-seven fan-like spreading inclined pipes, 26 in. c. to c., were driven in. Each group consisted of eight or nine pipes varying in angle of inclination so that the area allotted to the pipe was properly impregnated (Fig. 8). While the work progressed it appeared that the range of each pipe was greater than conservatively predetermined in the laboratory. Since almost every one of the 202 pipes driven had a different angle to allow for recesses in the foundation, for the column footings in front, or for the areas between the column footings, special pipe detail cards were given to the foreman showing base dimensions in relation to the working lines, number of stages and number of gallons injected per stage. From these cards the daily and weekly progress reports were made. Table 1, as submitted to the owners and consulting engineers, shows that almost 40,000 gal. (about 2,000 gal. less than estimated) of chemical were injected through 202 injection pipes in 43 working days. The average pipe length was 32.5 ft. The average driving footage per day into the highly compacted subsoil was 153 lin.ft. The injection of the chemical was going on while driving in or withdrawing the pipes. Average daily pumpage was 920 gal. for an eight-hour day. After withdrawal, each pipe was placed on a rack for inspection, and, while being carefully washed out, the non-clogged-up perforations of the point were counted by the inspector, who recorded the daily performances under the contract. Sixty-five to 75 per cent is considered a normal or good average of "open perforations" after withdrawal from the solidified area. The records show an over-all percentage of open perfora-

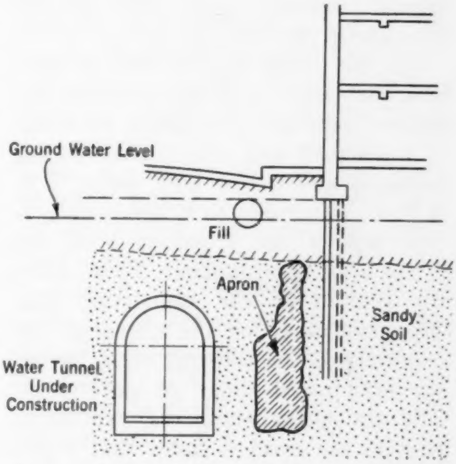


FIG. 7. Apron of Solidified Soil to Prevent Movement of Existing Pile Foundations

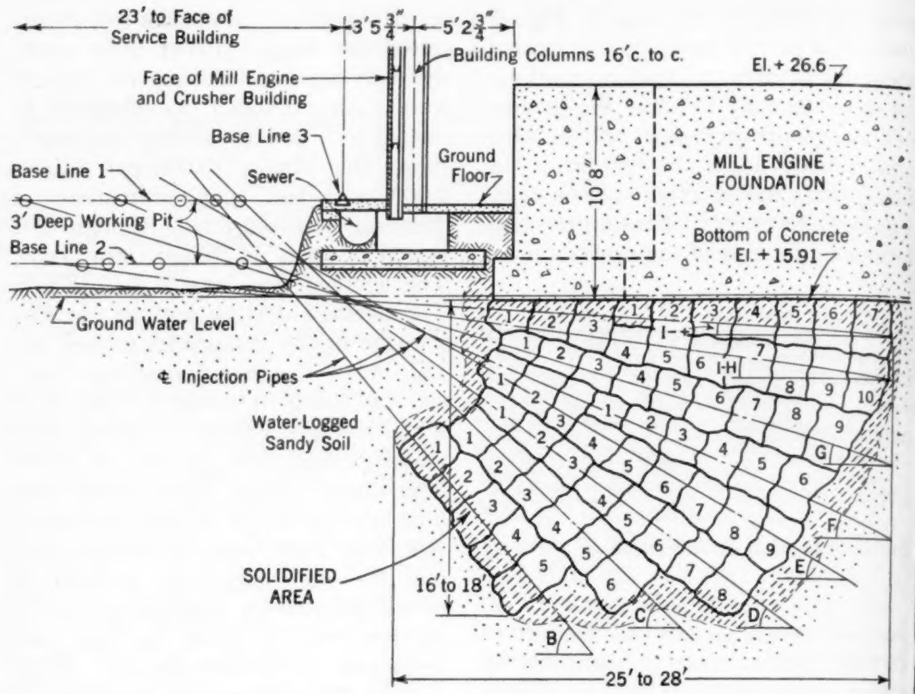


FIG. 8. Chemical Solidification to Stop Settling of Foundation Under Floor Carrying Heavily Vibrating Machinery

tions of more than 70 per cent, a positive proof that both chemicals were evenly injected into the ground throughout the contract area.

As the work approached completion, the owners and the consulting engineers' representative had a floor slab at a selected spot inside the building removed and a test hole, about 3 ft. × 7 ft., excavated to a depth of 5 ft. The top of the solidified area was found to be approximately 18 in. above the bottom of the foundation mat. This indicated that the chemicals had overreached the contract area, beyond the anticipated range of penetration. The consulting engineers' official report to the owners states that a pick was required to remove the solidified ground, and that it appeared from the results obtained that "good impregnation was secured," and that it was of "fairly uniform consistency."

The job was completed before the given time limit had expired. The approximate unit cost of the job could not be determined accurately because the contract was on a force-account basis, and the owners' actual detailed expenses were not available. It appears, however, that the actual cost per cubic yard of soil solidified did not run beyond \$23, which is not much more than that of good reinforced concrete. The low unit cost of this job was made possible by the excellent co-operation rendered by the owners' representatives and by the very understanding attitude of the consultants, who were interested in this unusual contract, the

TABLE 1 (SEE FIG. 8)

Weekly Progress Reports—1943

Week	No. of Pipes Driven	Chemical No. 1 Pumped *gal.*	Chemical No. 2 Pumped *gal.*	Pipe Driven *ft.*	*in.*
August 10–14	17	1,473	820.8	547	11
August 15–21	25	2,634	2,058.6	841	4
August 22–28	28	2,743	1,949.7	824	10
August 29–September 4	40	3,787	2,970.4	1,294	10
September 5–11	35	4,033	2,910.8	1,127	5
September 12–18	38	5,519	4,061.7	1,284	4
September 19–24	19	2,708	1,870.1	643	7

Summary:

202 pipes driven and withdrawn in 43 working days.
Chemicals Injected: 22,898 gal. No. 1; 16,640.3 gal. No. 2.
Average Pumpage: 920 gpd.

first large-scale subsoil chemical consolidation in the United States. The latest report, made by the U.S. Sugar Corporation's engineering department seventeen months after completion of the foundation improvement, gives level readings made at special reading points on the mill engine and crusher foundation above the solidified area (while the newly-repaired and installed machinery was working) and shows that no new settlement had taken place. The data of this survey will be compiled and made available after several years of observation.

Chemical Sealing of Leaking Concrete Structures

Characteristics

Stopping leakages in concrete and old brick or masonry walls or sealing pervious strata of rock foundations of large dams is effectively accomplished by injection of the Joosten chemicals. These operations require procedures different from those for soil solidification and the equipment consists of especially developed injectors and high-pressure pumps and connections.

Basically, the same chemicals as described before are injected into predrilled holes, the diameters of which will depend on the thickness of the walls and on other considerations. The holes are located so that they intersect the leaking seam or crack in the concrete; they are not drilled through the wall. Inserted in the holes are injectors selected from a variety developed by the author and his long-time associate, Lawrence Scully, to suit varying conditions. After the injectors are fastened and tightened against any possible hydraulic head or inner pressure created by the gradual filling of the voids with the gel, the first "shot" of Chemical No. 1 is given. This forces the water out of the seam. Chemical No. 2 is then injected and the sealing gel is formed immediately upon contact of the two chemicals with each other. The gel gradually fills the voids of the cracks and fissures; the pumping action pushes and packs the gel firmly. The fact that only small quantities of chemical, measured carefully, are fed at a time permits application of very high pressures without disruption of the concrete. To avoid

clogging the system, great care must be exercised by the operator not only in selecting the right spot for the injection holes in relation to the leaky crack, but also in handling the high-pressure pumps and the hand-operated valves.

By this internal sealing method, even against great hydraulic heads, difficult and troublesome leaks, which could not be sealed by conventional grouting, have been made watertight. It should be mentioned, however, that wherever cement grouting appears to be effective, particularly if large voids are encountered, it should be tried first. The Joosten process does not attempt to compete with concrete or cement grouting. Its field starts where the limits of practical use of concrete or cement grouting are reached, and where special problems and unusual conditions prevail.

Equipment, Supervision and Labor

The equipment used in chemical sealing varies little from that required for a soil solidification job, except that instead of the well-point type pipes, specially designed Y and straight injectors are needed. These are furnished with high-pressure, hand-controlled valve attachments for quick disconnection when switching back and forth from one chemical to the other. A pneumatic jackhammer of the lightweight type and complete drilling equipment are needed for drilling the holes in the cement before injection.

As in soil solidification jobs, careful planning by experienced engineers and a foreman familiar with the work and the equipment are needed. A four-man crew made up from local labor can handle the job, although more men will speed it up and make it more economical.

Chemical Sealing Jobs

To date the following chemical sealing jobs have been carried out by the author and his associates:

(1) Sealing a leaking tunnel stub and bulkhead of the Chicago freight tunnel system only a few hundred feet away from the river, against a head of about 40 ft. (Fig. 9). The very old concrete was honeycombed, with one construction joint at the ceiling, in a rather hopeless condition, leaking over the full length of the ceiling, and other leaks through the bulkhead as well as at the junction with the tunnel walls. Maximum pressure applied momentarily was 2,000 psi. About 15 gal. of chemical were pumped into an area requiring fourteen holes.

(2) Sealing one badly leaking panel of an Ambursen-type hydro-electric dam in the Northwest. Various costly attempts to stop the leaking of about 15 gpm. at this bay had failed. A second heavy concrete slab, poured several years before as a reinforcing support of the existing inclined main slab, did not stop the leaks: seeping along the path of least resistance, the water found its way upward between the old and new concrete slabs, creating an ice grotto and deterioration during winter weather. After the injection of 520 gal. of chemical into 115 holes drilled checkerboard-like at about 22 to 24 in. c. to c. through the secondary and halfway into the original inclined slab, a completely tight job was obtained. The rather excessive amount of chemicals pumped is an indication that quite a large area of voids existed between the two slabs and at the buttress haunch joints. Inspections in the following summer and after another very hard winter showed the panel still tight and dry.

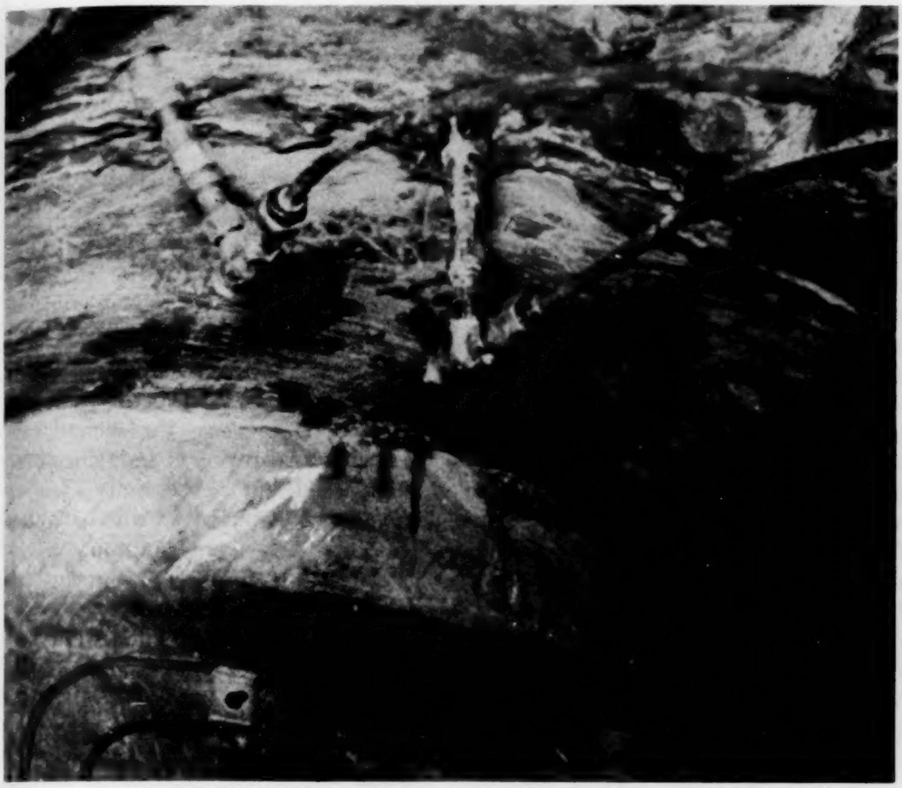


FIG. 9. Chemical Sealing of Old Tunnel Lining—Hardened White Gel Along Ceiling Construction Joint, With Injectors Still in Place

(3) Sealing a very damp and leaking subterranean valve chamber for a village water works in Illinois. Previous attempts to seal cracks and ground water leaks in the seven-months-old concrete in the four walls, corners and at the entrance of the 36-in. cast-iron main and some honeycombed area had brought no results. After one week of careful injections, and even re-injection of the chemical at particularly stubborn spots, the chamber and the shrinkage joint around the pipe dried up.

(4) Sealing a 19-ft.-5-in. vertical crack clear through a 22-in.-thick wall of a large water reservoir just completed in Chicago, and not in use at the time of the sealing. The large crack apparently was caused by the settlement of one of the piers supporting the wall panel. Four injection holes were sufficient to fill the voids for the entire length of the crack. The sealing was done from the inside of the empty reservoir.

(5) Sealing a 40-ft. newly-constructed high circular hot feedwater tank (thin-walled concrete with prestressed steel wire as reinforcement). The condition of the 1.5-mil.gal. tank, which was already in use but not accepted by the owner because of leaks and honeycombed areas, was so bad that a 100 per cent seal could not be

expected. However, systematic checkerboard-like injections through holes barely missing the closely spaced reinforcing wire improved the tank so that it was accepted by the owners.

(6) Sealing a similarly constructed 2-mil.gal. tank near the shore of Lake Michigan, also in use for about six months after completion but not accepted. The concrete was very good compared with the other tank, but horizontal cracks of a total of more than 860 lin.ft. had appeared, mostly in the middle third of its height, caused by temperature changes; some cracks were damp, some leaked steadily under the 30- to 38-ft. head. Although it was hoped to obtain a completely satisfactory seal because of the good condition of the concrete itself, a few linear feet, not quite 1 per cent of the original 860 lin.ft. of leaks, are still moist at the face opposite the lake where the temperature variations are the widest. It appears that such thin concrete walls, about 6 in. on top and about 9½ in. near the bottom slab, require a different temperature steel design than used at this tank which had no outside vertical temperature steel at all. Regular monthly inspections are still carried on by the author to study the peculiar and stubborn behavior of the remaining moist crack.

(7) Sealing the underground retaining wall of a large power plant boiler house basement, about 40 ft. high, for a length of about 85 ft. and only about 200 ft. away from the Mississippi River. The concrete poured about 22 years ago had developed sizable cracks and leaks; the water collecting between the wall and tile brick lining followed the course of least resistance and squirted or gushed out at the decomposed joints of the tile. The owners removed whole areas of the tile lining to find the exact location of the cracks in the concrete. Holes to receive the injectors were drilled along the cracks and around the worst leaks. Where the holes during drilling hit pockets, the water often gushed out in an almost wild stream because of the high ground water level outside the wall. In such cases wooden plugs were temporarily driven in the holes and holes within a radius of 3 to 3½ ft. injected first. Encircled by these holes the bad ones were usually dry when the wooden plugs were removed. This sealing job was the second carried out for the owners; and, since both jobs turned out successfully, sealing jobs for the improvement of other plants are under consideration.

(8) Sealing another Ambursen-type dam in Missouri. The concrete poured more than 20 years ago was extremely porous and weak, particularly the inclined main slab and some of the haunches. At spots where injection holes were drilled, often whole areas almost 2 ft. square spalled off, exposing the heavy reinforcing bars. The water leaked in as though dripping through fine-meshed sieves. Such areas had to be treated with utmost care. An attempt was made several years ago to reinforce this inclined main slab over half of the bays by a heavy 6-ft. concrete slab poured against it from the downstream side. The leaks, however, continued; the water found its way upward, mainly between the old and the new concrete. Because of the urgency of the need for the dam in this important mining area, the utility owners ordered a drastic rehabilitation of the dam, and chemical sealing was specified to be done before the inclined main slab of the second half of the dam was to be reinforced by pump-creting in an additional 6-ft

FIG. 10. Sealing Leaky Crack in 45-ft. Reservoir, While Reservoir in Operation—Hydraulic Head at Crack, About 32 ft.—Dark Areas Still Leaking, White Areas Hardened Silica Gel; Dry Holes, Visible as Black Dots, Are Points From Which Injector Has Been Withdrawn

slab, similar to the work started years before. In addition to this work, the badly worn-off crest of the dam was "rejuvenated." All soft and loose concrete was removed, a horizontal construction joint 3 ft. below the crest was chemically sealed (Fig. 10), wire mesh was anchored in and a new 1- to $1\frac{1}{2}$-in.-thick wearing surface gunited on. The exceptionally good guniting work carried out by the general contractors, as well as the preceding chemical sealing, was done from 40-ft.-long movable cofferdams floated in position, weighted down by sand bags, and dewatered to a depth of from 4 to 6 ft. In the meantime, the work underneath the inclined main slab continued. While a definite drying up of almost all the bays treated was noticed, even while the injection of the chemicals was in progress, very stubborn leaks and whole areas often required two or more re-injections to make certain that the water-bearing seams were properly filled and sealed. However, it also happened that as some bays were sealed and dried up, and with the substantial form work to carry the new 6-ft. slab installed and ready for pump-creting, some old leaks started to leak again through fine new cracks. This was caused, according to general opinion, by the rapid cooling of the considerable mass of new concrete in the just pump-creted adjacent bays. The change of volume of the green concrete confined within rigidly connected buttresses, haunches and main slab released immense inner stresses resulting in new hair cracks. In order not to upset the carefully planned program for the chemical sealing work, the erection of the heavy 40-ft. form work, and particularly the pump-creting, all re-sealing work in the troublesome bays had to be done during night shifts or on Sundays.

Now, more than eight months after completion of all sealing work, the owners state that the work is fully satisfactory, and that it is planned to use this method on other structures requiring sealing work.

Conclusions

The foregoing is sufficient to show that chemical soil solidification and chemical sealing, planned and carried out by experienced engineers according to strict rules and based on simple preliminary laboratory work, will result in permanent and satisfying results. State-supervised experiments, made in periods of more than ten years by Dr.

H. Joosten, have demonstrated that subterranean solidified areas "exposed to all natural influences to be expected on any kind of underground construction" have retained their original crushing strength and sandstone-like qualities.

Every new job of this kind has brought us face to face with new problems and has uncovered new ways to simplify the method and the equipment and to bring down unit prices. The author would like to take the liberty here to comment that research in an entirely new field takes time, money and hard labor, which can no longer be furnished economically by individuals. A stage has now been reached where specialized research work should be taken over by a neutral, acknowledged research organization which has available the manpower and the laboratory facilities quickly and effectively to work out problems in soil solidification which reach into the sciences of physics, chemistry, geology and, most important of all, soil mechanics. This will relieve the planning engineer of expenses, burdens and responsibilities too great to be carried at times when the completion of difficult jobs requires his undivided attention.

Municipal Water Works Organization in Maryland

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Prepared for the A.W.W.A. Committee on Municipal Water Works Organization

Formation of Municipalities

In Maryland there is no constitutional provision regarding the formation of cities and towns. The General Assembly, the legislative body in Maryland, is the sole judge of whether or not a municipal corporation shall be created. The powers and responsibilities of any municipal corporation are outlined in the act creating it, which act can be amended by the General Assembly at any session.

The ownership and operation of municipal facilities are controlled entirely by legislative enactment. Without such legislation a town or city is without authority to own or operate a utility or to issue bonds for the construction of one.

Financing

Funds for constructing and expanding municipal water works in Maryland are obtained in the following ways:

1. By an act of the legislature defining the powers and responsibilities of the municipality.

2. By a special act of the legislature authorizing the issuance of bonds or other securities for this purpose.

3. By the so-called "5 per cent law," whereby a municipality, with the exception of the city of Baltimore, the Washington Suburban Sanitary Commission, the Anne Arundel County Sanitary Commission and the Baltimore County Metropolitan District, may construct or establish by purchase or condemnation or extend or alter water supply, sewerage, drainage and refuse disposal systems and maintain and operate the same. Subject to a referendum of the voters of the municipality, but not to any further act of the General Assembly, bonds may be issued for this purpose up to 5 per cent of the assessed value of the property in the municipality.

4. By the "Public Works Act," first passed at the special session of the General Assembly in December 1933 and continued by succeeding general assemblies. Under this law, which was originally enacted to encourage the construction of public works to reduce unemployment, the municipalities, etc., with certain counties excepted, and certain limiting provisions relative to certain locations, can issue bonds for public works projects to be carried out with federal aid. The manufacture, generation, transmission and distribution of gas or electricity are not included under the act unless a county or municipality already owned and operated gas and electric plants and systems on Dec. 1, 1933.

5. By permit of the Maryland State Board of Health. Under this act, if

the state board of health finds, upon investigation, that any of the waters of the state are being, or are liable to become, polluted in a way dangerous to health or in such a way as to be a nuisance due to lack of any, or only a partial, system of public water supply, sewerage or refuse disposal, or if, because of the absence of such systems, it finds the health or comfort of a community is sufficiently prejudiced, it may issue an order to the county, municipality or district involved to construct within a specified time the necessary works to eliminate the objectionable conditions. Under such an order of the state board of health, the municipality, etc., subject only to the approval of the governor and the attorney general, may issue the necessary bonds to finance the necessary construction up to 2 per cent of the assessed value of the property within the municipality. Such bonds are in addition to and irrespective of any other borrowings of the particular municipality.

As far as is ascertainable, limitations of indebtedness of municipalities are fixed in all or nearly all acts which authorize the issuance of bonds or other securities for financing public works by them, except that the county, municipality or public corporation, not excepted or specifically limited by name, apparently is not limited under the "Public Works Act" in the amount it may borrow as long as the other provisions of the act are complied with—principally, that the municipality, etc., enter into a contract for a grant of money for the public works project with a federal agency.

Certain conditions are imposed by statute upon the sale of public securities except when issued by the state of Maryland, by the city of Baltimore or by housing authorities. Securities issued in anticipation of tax receipts, refunding bonds, bonds up to $25,000, bonds sold to the U.S. government or an agency thereof, and, under certain conditions, bonds issued in connection with federal aid projects are also not subject to the said statutory conditions.

Briefly the conditions are:

1. Bond issues must be advertised and sold to the highest bidder. If all bids are rejected the bonds may be sold within 30 days at private sale at a price not less than the highest bid at the public offering.
2. Bonds must be serial bonds.
3. Bonds for maturation later than certain specified maximum periods may not be issued. In the case of water systems this is 40 years.

Regulatory Bodies

While the Maryland Public Service Commission has full jurisdiction over private water companies, being identical with that exercised over electric and gas utilities, it does not have control over municipally-owned systems except as follows:

> Whenever the commission shall be requested in writing by any county, sanitary district, or municipal corporation of this state to fix or alter the rates that shall be charged for water supplied to persons or corporations within its county, sanitary district, or municipal boundaries by any other county or municipal corporation, the commission shall have as full jurisdiction and power to pass an order fixing or altering such rates as if the county or municipal corporation supplying such water outside its county or municipal boundaries were a "water company," as defined by this sub-title. Nothing contained in this section shall be construed to give said commission jurisdiction to order or compel extension of water service by such county or municipal corporation supplying water outside its county or municipal boundaries.

* Laws of Maryland, Chap. 810, as approved Apr. 16, 1914.

Permits must be secured by all municipalities, etc., from the state board of health to construct, alter materially or extend their water system. All construction must be in accordance with plans approved by the state board.

Should the state board of health find upon investigation that any water supply system is not being operated in such a manner as to produce satisfactory results from a sanitary standpoint it is obliged to issue an order to the proper officer having charge of or owning the system to take such steps within a specified time as are necessary to secure the required results. Upon failure of the owners of the system to meet this requirement the state board of health may order them to appoint and pay the salary of a competent person approved by the state board of health to take charge of the system and to operate it so as to secure the results demanded.

Local Organization

There is no specific form of municipal water works organization in the state. Eleven municipalities having a population of over 5,000 were written to and replies were received from nine. Three are sanitary districts governed by commissions, in one case the county commissioners, who have the authority and responsibility of setting up their own organizations as they see fit. All of the others are governed by a mayor and city council, members of the latter being variously known as councilmen, aldermen, or, in one case, commissioners.

In the municipalities, other than the sanitary districts, the water department is under the supervision in one case of an elected commissioner of water and electric light; in another case under a superintendent under the direction of the city engineer, both of whom are appointed by the mayor with the approval of the aldermen; in the third case by the mayor and council acting as a board of directors; in two cases by a commission of three persons appointed by the mayor and confirmed by the city council; and in the last case by a water engineer under the chief engineer of the city, both of whom are appointed by the mayor.

Of the six municipalities, other than the sanitary or metropolitan districts heard from, bills are sent out by the water works' own fiscal organization in four cases and collected by it in three cases. In three cases water revenues become municipal general funds and in three cases they are used exclusively for water works purposes. In the case of the two sanitary districts, the Washington Surburban and the Anne Arundel County, the water revenues, theoretically at least, are used for water works purposes only as they are organized specifically for the purpose of furnishing sanitary services and have nothing to do with the other public services which are usually municipal functions.

In the case of the Baltimore County Metropolitan District, the city of Baltimore has complete control of supplying the water to the consumers of Baltimore County and carrying on the management of the system as if it were an integral part of the city system. Baltimore County levies taxes and benefit assessments for the purpose of meeting the interest, or other amortization sinking fund requirements of the bonds issued to finance the construction of the water mains carried on by the Baltimore County Metropolitan District. The establishment of rates, the billing and collection of water charges and the maintenance of the Metropolitan District water system are thus carried on by the city of Baltimore. The Mary-

land General Assembly, however, at its 1945 session enacted a law requiring the city of Baltimore to supply water to the Baltimore County consumers at cost.

Comments

From the constitutional and regulatory standpoints the author sees no particular need for any change relative to municipal water works.

Under the existing legal system a municipality can have any kind of water works organization that it wants and that, in the author's opinion, is as it should be. We may not like or approve a particular water works organization but if the people who pay for it are satisfied, who are we to gainsay them? If the people don't like it, they can readily and legally make the necessary changes.

The regulatory powers of the Maryland State Board of Health and the Public Service Commission seem to be ample and from a practical standpoint work out satisfactorily.

An interesting feature of municipal water works management in Maryland is the large percentage of the population served by the municipality of Baltimore and the sanitary and metropolitan districts. According to the 1940 census, and the percentage is even greater now, these organizations served 1,094,925 people out of a total population of 1,231,721 in municipalities of over 5,000 population. This, of course, simplifies the water works management problem in the state.

The natural features of the state—size, topography, surface and underground waters, geology, climate, etc. —and the existence of large metropolitan centers lend themselves to the feasibility of extending public water supplies to a much larger percentage of the area of the state than is the case in many states. This possibility has not been fully realized as yet, although a preliminary step toward extending the public water supply of one of the sanitary districts into certain of the adjacent rural sections by extending the boundaries of the district has recently been approved by the 1945 session of the General Assembly, and some communities also serve water to nearby consumers located outside the municipal boundaries.

It is believed, however, that because of the favorable conditions public water supplies can be extended into the rural areas of the state to a far greater extent than is done at present. Possibly a subsidy may be needed in some cases. This might be from county, state or even, in special instances, federal sources. When the direct relation between the public health and an adequate and safe public water supply is considered, there would appear as much justification in many instances for providing assistance where necessary for the purpose of extending the public water supply as there is for extending financial assistance for building local highways and drainage, for constructing an electric power system, for expanding the school system, or for any other public service or function required in the public interest. The favorable financial and public health aspects in the case of water works will, in many cases, certainly be more demonstrable as the providing of a public water supply will bring about the development of the area served and hence result in an increase in the wealth of the state and at the same time pay, or go a long way toward paying, its way. The providing of a public water supply to rural communities will also compare very favorably with other accepted

subsidized public activities in improving the amenities of rural life.

While fully recognizing the right of each community to spend its public revenues as it sees fit in accordance with law, water works personnel will find, in the author's opinion, that it would be easier to secure the necessary funds for the proper expansion and operation of their water systems, if they convinced the authorities that water works revenues should be kept in a water works account and used only for water works purposes. There is no sound reason why water works money should go to finance other public functions. Convincing public officers of this is a matter of local education, but a program toward that end should also result in a greater local appreciation of the water works and of the persons operating them, who unfortunately seem by nature to be inclined "to hide their light under a bushel." This is not peculiar to the state of Maryland.

EXTENSION OF BOUNDARIES OF SANITARY DISTRICT INTO RURAL AREAS OF MARYLAND

The General Assembly of Maryland at its 1945 session enacted a law extending the boundaries and jurisdiction of the Washington Suburban Sanitary District, which will result in a piped public water supply being made available to a sizeable rural area adjacent to the Maryland suburbs of Washington.

These rural areas, while still agricultural to a very considerable degree, contain numerous small villages and communities and even some lot and small estate developments, so the population density is in excess of that which one generally expects of rural sections.

Because the area added to the sanitary district was adjacent to the Washington-Maryland suburban area, actually being part of it at some locations, and therefore part of the next area into which the metropolitan population will expand, it was believed forward looking and logical to extend water service into the area on the same financial basis as to other parts of the sanitary district. The District of Columbia is now nearly built up and it is not feasible to expand its boundaries, so future growth in population centering on Washington has to take place principally in nearby Maryland or Virginia. Therefore the extension of public water service to the newly added area will not only enhance the amenities of life for the present inhabitants but will serve as a material inducement to present and future inhabitants of the Washington metropolitan area to settle in the Maryland countryside.

Sewerage service as well as water service will be extended when practicable into the newly added areas. However, because of the relatively diffused population, because of the fact that habitations will be on tracts of a size that will permit fairly successful operation of individual family disposal systems, because of the nature of the construction required for sewers (depth, gravity, topography, etc.) and because of the fact that the commission's existing trunk sewers are not now generally extended to the inner limit of the newly added area, whereas its water system is, sewerage service to the newly added areas will in general be provided at an appreciably later date than will water supply.

The extending of the public water supply into the area newly added to the sanitary district is not the limit of what can be done, in the author's opin-

ion, toward providing a public water supply in rural sections in this vicinity. In fact studies already made indicate that it is financially feasible to serve considerably more extended and more predominantly rural areas in central and southern Maryland with public water supplies. This generally cannot be done, at the same rates which prevail in the sanitary district, if it is planned to construct a system furnishing comparable service to that of the commission's existing system. However, it can be done in one area investigated in some detail, and it is believed from inspection in quite a few others, at rates which will be very attractive to present and future settlers if consideration is given to the advantages of an adequate and safe water supply for all purposes, the elimination of the cost of constructing and operating an individual private water system and the value of fire protection and the savings incident thereto.

It is to be pointed out that the idea here outlined would mean the development of multiple supplies rather than a single supply. There would be no network or grid of water mains all over this part of the state, although eventually there will probably be some interconnections between and merging of various systems. It is believed, however, that there are enough potentialities in the situation to warrant the detailed study by pertinent state agencies of the subject as a regional water supply problem. Much of the water in the coastal plain section might come from artesian sources.

In order to promote the amenities, to induce the settlement and to bring about the proper development of rural areas adjacent to large centers of employment, such as Washington and Baltimore, it is believed that it would be good public policy on the part of the state to assist financially where necessary to extend public water supplies into such rural sections. The public health would be advanced by the creation of supervised public water supplies and the material wealth of the state would be increased by the development of the rural areas by the more dense settlement of them and all that accompanies such settlement. Other states in the past have given inducements to bring about the development of their lands, so while this may be a different way to do it, it does not differ in principle and therefore has plenty of precedent. As it is believed that this is a state and local matter, no reference is made to any similar procedure followed by the federal government in the past or to the "General Welfare" clause of the Constitution. Other states, especially those having large metropolitan areas, which have not already done so, might well look into what can be done toward expanding public water supplies into their rural sections.

Water works are generally revenue-producing, not revenue-absorbing, public agencies. Such revenues should be used where practicable to improve and expand the water system so as to bring about the development of the community and make it a better place in which to live (incidentally, this generally results in more revenue), rather than be used to support some revenue-absorbing public function.

A Variety of Water Problems Solved by Chlorine Dioxide Treatment

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A paper prepared for presentation at the A.W.W.A. Annual Convention

THE chlorine dioxide process for water treatment, originally developed to solve the problem of tastes and odors caused by phenolic and algae contamination at Niagara Falls (1, 2), has since been applied to a variety of water conditions.

The use of chlorine dioxide in water treatment is based upon its unusually high oxidizing capacity, which is 2½ times that of chlorine. Chlorine combines with phenols, resulting in the characteristic "chlorphenol" effect, but chlorine dioxide oxidizes them to tasteless end products. Chlorine dioxide also reacts more rapidly with organic contaminants. These properties make chlorine dioxide useful in water works having problems of the following types:

1. Unpleasant tastes and odors resulting from the chlorination of phenolic wastes and algae. The addition of chlorine dioxide rapidly eliminates these tastes and odors.

2. Inability to pre-chlorinate, owing to the intense tastes and odors developed. Post-chlorination alone is usually unsatisfactory, because it leads to filter difficulties and also because it gives poor disinfection control. When chlorine dioxide post-treatment is used, pre-chlorination without regard to taste and odor is possible.

3. Inability to maintain a chlorine residual. Slowly reacting organic compounds are not oxidized by pre-chlorination but pass through into the distribution system, where they destroy the chlorine residual. Chlorine dioxide reacts rapidly with these compounds in the clear well. Therefore, the addition of chlorine dioxide with an excess of chlorine will assure an active residual in the water.

The Problems

These applications of chlorine dioxide may be illustrated by describing its use in several communities now supplied, for the first time, with a continuously safe and palatable water.

The general procedure, which has already been described in detail (1), involves pre-chlorination, for disinfection, followed by treatment with chlorine dioxide in the clear well, for removal of tastes and odors. Although chlorine dioxide is a powerful bactericide, chlorine pre-treatment is more economical for disinfection (2).

The chlorine dioxide is generated by connecting the feed line of a Wallace & Tiernan chlorinator to a mixing chamber, into which is metered a solution of sodium chlorite. The reaction of chlorine and sodium chlorite yields chlorine dioxide which then enters the clear well. This general procedure may be varied to meet special conditions (see table).

TABLE

Chlorine Dioxide Treatment Under Various Conditions

Location	Type of Water	Pre-chlorination *ppm.*	Cl in Settling Basin *ppm.*	Cl Under Filters *ppm.*	ClO_2 Dosage *ppm.*	Post-chlorination *ppm.*	Residual *ppm.*
Niagara Falls	Clear, with phenols and algae	1.5	0.4	0.2	0.5–0.75	—	0.2
Eastern Pennsylvania	Organic with some phenol	2.0	0.5	0.2	0.4–0.5	—	0.4–0.1
Western Massachusetts	Decayed vegetation and algae, gasoline and kerosene	1.5	0.3	0.2	0.5	0.1	.20
South Carolina	Algae	1.5–5.0	0.1	Trace	0.5	0.6–0.7	0.4–0.1
Maine	Highly colored with decayed vegetable matter, effluent from sulfite and kraft paper mills and upstream town sewage	4.0–15.0	0.8–1.0	0.5–0.6	1.25*	0.75	1.5–0.4

* This high dosage is required because of severe conditions found when the new process was introduced. When the organic material in the distribution system has been removed, the post-treatment will gradually be reduced to a more economical point.

Niagara Falls

The water at Niagara Falls suffers from seasonal contamination by phenolic wastes and algae. This condition is intensified by the fact that the phenolic pollution comes in surges rather than at a constant rate. Break-points were difficult to detect and control, and the "chlorphenol" taste and odor became so pronounced in one plant that frequent shut-downs were necessary. This problem was solved in the following manner: The water is pre-chlorinated to disinfect, without regard to taste or odor, a chlorine residual of 0.2 ppm. under the filters being obtained. The normal dosage required is 1.5 ppm. chlorine. Following clarification and filtration (the use of carbon has been eliminated in this procedure), chlorine dioxide is introduced at the clear well in a dosage of 0.5 to 0.75 ppm. In addition to the improvement in the quality of the water, this process has been found to eliminate the need for careful break-point measurements at Niagara Falls and has also cut chemical costs.

Eastern Pennsylvania

Another type of water problem is found at a town in eastern Pennsylvania. Here the water, supplied by the Delaware River, suffered chiefly from severe organic contamination plus a small amount of phenol. Before the plant changed to the chlorine dioxide process, the treatment involved pre-chlorination to the break-point, carbon in the settling basin, alum for floccing and soda ash for pH control.

This treatment did not completely destroy the unpleasant qualities of the water, described as "chlorinous with some bogginess." This was particularly noticeable in the distribution system. Moreover, it was difficult to carry a chlorine residual, since the 0.25 ppm. which left the plant was rapidly dissipated in the distribution system.

When the chlorine dioxide process was introduced, the pre-chlorination was adjusted to a quantity sufficient to disinfect and to maintain a 0.2-ppm. residual under the filters. The carbon has been eliminated; the alum and soda ash treatment remain the same. The dosage of chlorine dioxide in the clear well is 0.4–0.5 ppm. This treatment has cleared up the disagreeable taste and odor, and the water now has a residual of 0.1–0.2 ppm. even at the end of the distribution system.

Western Massachusetts

At a city in western Massachusetts, the heavy organic contamination from decayed vegetation and algae is complicated by gasoline and kerosene dumped into the watershed from a nearby army air base. Before the introduction of the chlorine dioxide treatment, pre-chlorination was not possible because it intensified the tastes and odors and therefore required so much carbon that the filter runs were excessively shortened. The process used, therefore, was aeration, alum flocculation with lime to control the pH in the basin, filtration and post-chlorination in the clear well for disinfection. There was a very narrow margin between the amount of chlorine required for disinfection and the amount which would intensify the disagreeable qualities of the water so that it became entirely unpalatable.

The introduction of the chlorine-chlorine dioxide treatment permitted adequate disinfection and improved the quality of the water. In order to eliminate the difficulty caused by the gasoline and kerosene, a small amount of carbon (3.0–4.0 ppm.) is added just before filtration.

South Carolina

A similar type of water problem existed at a town in South Carolina, where the water is very soft and extremely turbid and is troubled with no industrial contamination but with very severe algae conditions. Pre-chlorination could not be used because of taste and odor difficulties. The process in use—coagulation, filtration and post-chlorination—did not completely avoid unpleasant tastes and also could not maintain a residual in the distribution system. Chloramination was tried in an attempt to solve this problem but failed because it was found that, if not closely controlled, free ammonia entered the lines and promoted the growth of organisms. The formation of chloramines also slowed up the action of the chlorine, decreasing the effectiveness of disinfection.

This difficulty was solved by introducing the chlorine-chlorine dioxide treatment. To insure the maintenance of a chlorine residual in the distribution system, an excess of chlorine is added with the chlorine dioxide to the clear well. In this way, a residual of 0.1 ppm. chlorine is maintained at the end of the distribution line.

Maine

A city in Maine has water that is soft and generally highly colored. The drainage area of the water supply, the Penobscot River, includes a swampy area, so that the water is contaminated

with considerable organic material, including decayed vegetable matter and algae. The stream is also contaminated by the wastes from several upstream paper mills, both sulfite and kraft, and by the sewage from some upstream communities.

These contaminants give the water a swampy taste and odor, intensified by the addition of chlorine. Super-chlorination was not adequate and, in order to obtain a water that was at all palatable, it was necessary to resort to chlorination at three different points. The first small dose of chlorine was followed by treatment with alum and lime. The water was then aerated and thoroughly mixed in a flocculator. Carbon was added and the water was settled for two and one-half hours. After settling, enough chlorine was added in the line leading to the filters to give a residual of 0.2–0.3 ppm. under the filters. After filtering, the pH was again adjusted in the main clear well, and a third dose of chlorine was added at the exit end of the main clear well as it was delivered to the small auxiliary well.

This treatment did not succeed in giving an entirely palatable water. Moreover, the chlorine was rapidly dissipated after each of the three additions. There was no residual after 30 minutes in the settling basin; there was about 0.1–0.2 ppm. under the filters, and only a trace leaving the plant. No residuals could be detected at any point in the distribution system. In addition to the danger of secondary pollution, the process also caused operating difficulties, since it was not possible to keep down organic build-up in the basin, wells and distribution system.

The chlorine-chlorine dioxide treatment is now being used here, but, because of the very high degree of pollution, larger doses of chlorine are required than in other cases. Pre-chlorination is adjusted to give a residual of 0.5–0.6 ppm. under the filters, the dose being in the order of from 4.0 to 15.0 ppm. chlorine. The increased dosage occurs in the warm season when the natural demand of the water increases. The post-treatment with 1.25 ppm. chlorine dioxide is also higher than elsewhere. This treatment with chlorine dioxide not only removes the taste and odor in the finished water but also makes it possible to maintain an active chlorine residual throughout the entire distribution system. It is expected that this post-treatment will be reduced to more economical figures when the distribution system is cleared of organic material and taste producers.

The chlorine dioxide process in this city achieves a more satisfactory water in every respect. The more effective pre-chlorination results in a better color and improves the floc formation, which in turn results in longer filter runs. Also, the filters are kept in better condition since organic growths are avoided. The water is efficiently disinfected, resistant to secondary pollution and entirely palatable.

Summary

In the course of developing the installations described above, temporary operating difficulties have sometimes been encountered. These have demonstrated that certain controls are necessary for the successful application of the chlorine dioxide water process.

In the generation of chlorine dioxide by the reaction of chlorine and sodium chlorite solution, it is first of all essential that a sufficient excess of chlorine be used. The theoretical ratio of chlorine to chlorite is 1 : 4. The recommended ratio is 1 : 2 or less. That is

to say, there should be at least a 50 per cent excess of chlorine over the theoretical in order to obtain efficient evolution of chlorine dioxide. Otherwise, incomplete reaction of the chlorite may occur.

It is also important to regulate properly the flow of water through the chlorinator. If this flow becomes too great, the concentration of chlorine in the effluent will be decreased. It has been found that decreasing the concentration of chlorine causes a rise in pH and thereby decreases the efficiency of the reaction. As an example, when one plant encountered difficulty, an analysis showed that the water pressure through the chlorinator was so high that the chlorine concentration was reduced to 0.2 g. per l. and the pH was raised to 5.5. Under such conditions, very little chlorine dioxide was formed. When the water pressure was reduced, the chlorine concentration in the effluent increased to 0.8 g. per l., the pH dropped to 2.5, and within four hours the difficulty had disappeared.

Once the proper concentrations and proportions of chlorine and chlorite have been achieved, the process operates simply, with a minimum of control, to give a palatable, safe water under the variety of conditions described.

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Utica, New York—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1940

THE Utica Board of Water Supply is in charge of the operation of the municipally-owned water system serving the city of Utica and contiguous area. The city is an important trading and industrial center located in the central part of the state on the banks of the Mohawk River. In addition to large textile mills the principal industries include the manufacture of metal and wood products, heating and ventilating equipment, clothing and fire arms. The State Barge Canal parallels the Mohawk River through the city.

The population of the city, as of the federal census of 1940, was 100,518. The water system serves a considerable area of surrounding territory, including the communities of Whitesboro, New Hartford, Oriskany, New York Mills, Yorkville, Frankfort and Deerfield and the towns of Marcy, Trenton and Schuyler. The population served at the date of the study was estimated to be 120,000. The consumption during 1940 averaged 12.8 mgd. or about 100 gpd. per capita.

Development of the Existing System

The forerunner of the present water system in Utica was created as the Utica Aqueduct Company by an act of the state legislature in April 1802. The supply was obtained from springs within the present city and conveyed through a log aqueduct to a central point. This aqueduct continued to supply part of the inhabitants until 1824 when it was severed and the supply cut off by the construction of the Erie Canal. From 1824 to 1834 local springs and wells were the only sources of water. In 1832 the Utica Water Works Association was formed, and, in 1834, the association laid a line of $2\frac{1}{2}$-in. pipe from springs to the central part of the city. This served water to a part of the city until 1850 when it was abandoned.

In 1845 the Utica Water Works Company was formed. In 1849 contracts were let for the construction of a complete water works system. A supply was secured from a well at Starch Factory Creek and was conveyed through a 12-in. brick conduit, about 9,000 ft. long, to a reservoir in the city. Transmission from the reservoir was through a 12-, 8- and 6-in. cast-iron main branching into a number of 3- to 5-in. distribution mains. These works were completed and placed in operation in 1849. While the supply works, brick conduit and reservoir have been retired, many of the distribution mains, hydrants and valves are still in service.

In 1854, the 800,000-gpd. consumption from the spring was found inadequate and the present No. 1 Reservoir was constructed. Other impounding and distribution reservoirs were constructed from time to time, three of which have been retired over the years.

In 1938 the Consolidated Water Company, successor to the Utica Water Works Company, in existence for 89

Distribution Storage Facilities of Northern Supply System

Name	*Supplied From*	*Supplies*
Marcy Equalizing Standpipe	Hinckley	Reservoir Nos. 6 and 11
No. 11 Marcy Distributing	Hinckley	Intermediate and low service
No. 6 Bacot Distributing No. 7 Bacot Forebay	Hinckley and Reels Creek	Low service
South Hill Standpipe	Reservoir Nos. 6 and 7	Turnbull Heights
No. 10 Whites Town Distributing	Intermediate service	Whitesboro low service
Whitesboro Equalizing Standpipe	Low service	Whitesboro low service
Old Oriskany Standpipe	Low service	Oriskany low service
New Oriskany Standpipe	Low service	Oriskany low service

years, was purchased by the city. The present supply is by gravity from impounding reservoirs grouped in two main systems on opposite sides north and south of the city. Distribution is in three services, the low service, which embraces the major portion and the congested section of the city, and the relatively minor intermediate and high services.

The northern or West Canada Creek supply system, developed since 1905, consists essentially of the Hinckley Reservoir on West Canada Creek and the Tracy Reservoir on Black Creek. The Hinckley Reservoir, 18 mi. northeast of the city, was constructed by the state in 1916 to serve chiefly as a feeder for the State Barge Canal. The city has the right to take 50 mgd. from this reservoir. The Tracy Reservoir, constructed in 1906–1907, 10 mi. southeast of the Hinckley Reservoir, provides reserve storage to compensate for the supply taken from the Hinckley Reservoir when the flow of West Canada Creek is reduced to below the necessary requirements. Another small source in this system is the Reels Creek intake which diverts water from a small stream into two distributing reservoirs during a part of the year.

The southern supply system consists mainly of the Graefenberg Reservoir and Savage intake. The Graefenberg Reservoir, known as Reservoir No. 1, located about 2 mi. southeast of the city, was originally built in 1854 and raised in 1864–1865. It serves the high-service area on the south side of the territory with water secured from a small drainage area and wells. The Savage intake diverts water from natural drainage and springs and furnishes the supply to Reservoir Nos. 2, 4 and 5, the latter two of which also receive some natural drainage.

Distribution Storage Facilities of Southern Supply System

Name	*Supplied From*	*Supplies*
No. 2 Hopper Settled Storage	Reservoir Nos. 3, 4 and 5	Pumped to high or low service
No. 4 Golden Distributing	Natural drainage and Reservoir No. 3	Low service and Reservoir Nos. 2 and 5
No. 5 Cascade Settled Storage	Natural drainage and Reservoir Nos. 3 and 4	Pumped to high or low service
No. 8 New Hartford Equalizer	Reservoir Nos. 1 and 11	Intermediate service and pumped to high service
New Hartford Tanks	Reservoir No. 1 or pumped from No. 8	New Hartford high service

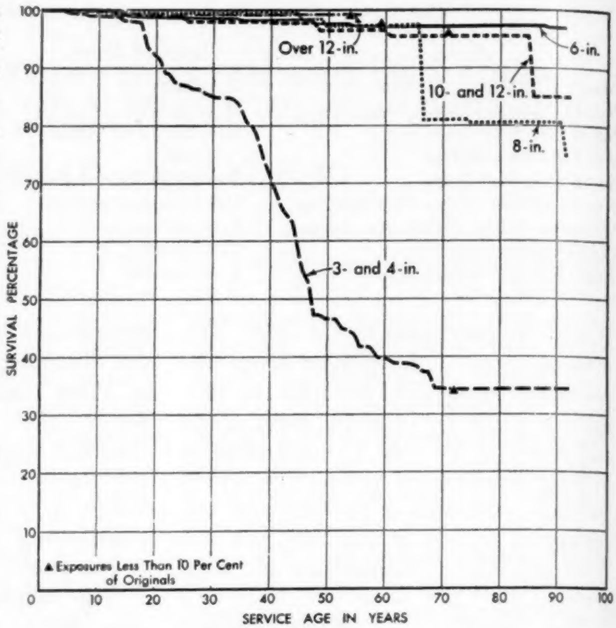


FIG. 1. Mortality Survival Curve—3–42-in. Cast-Iron Unlined Mains—Utica, New York

BASE: Feet	SURVIVAL: 1849–1940	
SIZE *in.*	EXPOSURES *ft.*	RETIREMENTS *ft.*
3 and 4	90,597	55,257
6	596,806	10,972
8	135,949	3,175
10 and 12	131,384	3,246
Over 12	205,064	1,557

Except in certain emergencies, or at times of low flows in the supply streams, the entire service is by gravity. At the Hinckley Reservoir there is located a 13-mgd. motor-driven booster pump used when the reservoir is considerably drawn down for Barge Canal use. At Reservoir No. 2 is a booster station in which are located two 5-mgd. and one 1-mgd. pumps, the first two of which pump from Reservoir Nos. 2 or 5 into Reservoir No. 4 or to low service or by operation in series into the high service. The 1-mgd. pump discharges into the high-service area.

From the terminus of a state-owned 42-in. pipe below Hinckley a 24-in. cast-iron line extends about 12 mi. to the Marcy standpipe, thence another 2 mi. to the Marcy Reservoir (distributing) and continuing about 2 mi. farther to the southwestern intermediate service. From the Marcy standpipe a 16-in. line extends 2.2 mi. to a connection with the 24-in. intermediate-service line and continues easterly as parallel 16- and 24-in. lines 2.5 mi. to the Bacot-Deerfield Reservoir Nos. 6 and 7. Reels Creek is connected to these reservoirs through a 20-in. main 1.5 mi. long. From these distributing reservoirs, Nos. 6 and 7, located a little over a mile outside the city limits, parallel 20- and 30-in. mains extend southerly into the city's congested area.

From the southern system a 12-in. main from No. 1, Graefenberg Reservoir, extends 1.2 mi. north to the high-service area. A 20-in. main extends 1.5 mi. from Savage intake to Reservoir No. 4 at the southerly city limits.

In the congested portion of the low-service area the pressures normally range from 60 to 80 psi. In the intermediate- and high-service areas the pressures range from 100 to 120 psi. The weights of the pipe in the supply

mains vary from Class C to 250-lb. centrifugal cast-iron pipe. Prior to about 1927 the distribution pipe laid consisted of Class B (since the adoption of such standard), and since 1927 150-lb. cement-lined cast-iron pipe has been standard. Pipes are laid with a cover of from 4 to 4½ ft. Unlined pipe shows a moderate amount of tuberculation.

TABLE 1

SUMMARY OF MAINS
UTICA, NEW YORK

Size, *in.*	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, *yr.*
3	Cast-iron unlined	27,552	2.34	22,632	28.31	4,920	0.46	1849	66.9
4		63,045	5.36	32,625	40.81	30,420	2.78	1849	62.9
6		596,806	50.77	10,972	13.73	585,834	53.46	1849	37.7
8		135,949	11.57	3,175	3.97	132,774	12.12	1849	38.6
10		37,773	3.22	2,399	3.00	35,374	3.24	1849	50.3
12		93,611	7.96	847	1.06	92,764	8.47	1849	28.3
16		31,979	2.72	0	0	31,979	2.92	1886	36.1
20		54,776	4.66	1,371	1.71	53,405	4.88	1885	41.2
24		112,694	9.59	186	0.24	112,508	10.27	1885	31.8
30		5,615	0.48	0	0	5,615	0.51	1924	16.5
42		900	0.08	0	0	900	0.08	1912	28.5
6	Cast-iron cement lined	5,069	0.43	0	0	5,069	0.46	1934	5.6
8		26	0.00	0	0	26	0.00	1938	2.5
12		1,216	0.10	0	0	1,216	0.11	1934	6.0
21	Steel	128	0.01	0	0	128	0.01	1934	6.5
30	Steel	500	0.04	0	0	500	0.04	1913	27.5
$\frac{5}{8}$	Lead	28	0.00	0	0	28	0.00	1913	27.5
$\frac{3}{4}$	Lead	148	0.01	0	0	148	0.01	1898	41.8
$\frac{3}{4}$	Wrought-iron	63	0.01	0	0	63	0.01	1913	27.5
1		442	0.04	409	0.51	33	0.00	1891	49.5
$1\frac{1}{2}$		1,210	0.10	1,210	1.51	0	0.00	1860	
2		1,702	0.14	1,239	1.55	463	0.04	1851	29.4
$2\frac{1}{2}$		2,877	0.24	2,877	3.60	0	0.00	1902	
$\frac{3}{4}$	Copper	31	0.00	0	0	31	0.00	1935	5.5
1		226	0.02	0	0	226	0.02	1935	5.5
$1\frac{1}{2}$		158	0.01	0	0	158	0.01	1935	5.5
2		4	0.00	0	0	4	0.00	1938	2.5
1	Galvanized steel lead-lined	98	0.01	0	0	98	0.01	1913	27.5
2		128	0.01	0	0	128	0.01	1913	27.5
6	Steel, bituminous lined and coated	470	0.04	0	0	470	0.04	1940	0.5
8		45	0.00	0	0	45	0.00	1937	3.5
30	Ingot-iron	500	0.04	0	0	500	0.04	1913	27.5
TOTAL		1,175,769	100.00	79,942	100.00	1,095,827	100.00		53.11
Percentage of Total		100.0		6.80		93.2			
Average Size, *in.*		9.46		4.60		9.81			

TABLE 1 (contd.)

Mortality Survival Ratios

Cast-Iron Unlined Pipe

Size, *in.*	No. of Feet	Period Covered, *yr.*	Percentage
3 and 4	90,597	91.5	33.902
6	596,806	91.5	89.945
8	135,949	91.5	74.214
10 and 12	131,384	91.5	84.752
Over 12	205,064	55.5	99.222
Total	1,159,800		

FIG. 2. Mortality Survival Curve—$\frac{5}{8}$–8-in. Meters—Utica, New York

BASE: Unit SURVIVAL: 1890–1940

Size *in.*	Kind	Exposures *Units*	Retirements *Units*
$\frac{5}{8}$	Disc	18,219	1,055
$\frac{5}{8}$	Piston	2,660	1,378
$\frac{3}{4}$–$1\frac{1}{2}$	All	776	0
2–8	All	377	0

As of the date of this study there were in the system 25,575 service connections, 3,874 valves, 1,884 hydrants and 21,622 meters. Active services were approximately 100 per cent metered with 80 per cent of the total water served being accounted for through the distribution meters.

Basis of Study

The records of installation and retirement of pipe within the city, with minor exceptions, are complete from 1849 to date and are kept in a main record book. Other record books of the early history and for the periods 1874–1888 and 1888 and 1902 are available for checks. The main supply lines are included in the studies of pipe but not the minor amount of distribution pipe outside the city limits.

The records of installation and retirement of valves have not been accurately kept up to date, so no study of these was initiated.

The records of meters are substantially complete from 1891 to date and are kept in card index form. Retired meter cards are retained in a separate file. From about 1882, when meters were first installed, through 1890 the records are not complete.

TABLE 2

Summary of Meters
Utica, New York

Size, *in.*	Kind	Number Installed	Number Retired	Number in Service	Average Age, *yr.*
$\frac{5}{8}$	Disc	18,219	1,055	17,164	23.3
$\frac{3}{4}$	Disc	422	0	422	26.6
1	Disc	237	0	237	23.5
$1\frac{1}{2}$	Disc	19	0	19	24.1
2	Disc	56	0	56	24.2
$1\frac{1}{2}$	Compound	51	0	51	20.1
2	Compound	112	0	112	21.0
3	Compound	35	0	35	22.0
4	Compound	48	0	48	20.9
6	Compound	28	0	28	15.6
8	Compound	8	0	8	14.4
3	Crest	4	0	4	33.2
4	Crest	5	0	5	34.9
3	Current	4	0	4	36.5
4	Current	2	0	2	31.0
6	Current	1	0	1	34.5
6	Detector	3	0	3	17.8
$\frac{5}{8}$	Piston	2,660	1,378	1,282	30.2
3	Piston	2	0	2	42.0
4	Protectus	5	0	5	20.7
6	Protectus	36	0	36	20.3
8	Protectus	24	0	24	20.3
4×1	Valve	8	0	8	18.0
6×1	Valve	2	0	2	22.0
$6 \times 1\frac{1}{2}$	Valve	37	0	37	12.1
6×2	Valve	4	0	4	20.0
Total		22,032	2,433	19,599	23.8

Mortality Survival Ratios

Size, *in.*	Kind	Period Covered, *yr.*	Percentage
$\frac{5}{8}$	Disc	50.5	8.984
$\frac{5}{8}$	Piston	50.5	9.732
$\frac{3}{4}$–1	All	43.5	100.000
2–8	All	43.5	100.000

TABLE 3

Summary of Hydrants
Utica, New York

Size, *in.*	Kind	Number Installed	Number Retired	Number in Service	Average Age, *yr.*	Period Covered, *yr.*	Mortality Survival Ratio, %
3–10	All	1,726	150	1,576	28.5	91.5	42.510

The records of hydrant installation and retirement are quite complete in card index form from 1849 to the present. Prior to about 1870 there were some discrepancies in retirements and between that date and 1910, some shifting of hydrants from one location to another. Since 1910 the record is definite and complete.

The installation and retirement of Class B facilities from 1849 to date are quite definite as to size, age, general detail and retirement of those taken out of service.

FIG. 3. Mortality Survival Curve—3–10-in. Hydrants—Utica, New York

BASE: Unit SURVIVAL: 1849–1940

SIZE *in.*	EXPOSURES *Units*	RETIREMENTS *Units*
3–10	1,726	150

Mortality Survival Study

Mortality studies were made of mains, meters and hydrants. Table 1 gives a summary of the pipe installed and retired and the amount remaining in service, as well as the average age, size, length of record and grouped mortality survival ratios. Figure 1 shows the mortality survival curves covering the record of the pipe grouped as shown.

Tables 2 and 3 are similar summaries of meters and hydrants, with Figs. 2 and 3 representing the applicable mortality survival curves.

Given below is a brief summary of Class B facilities, with the exception of pumping equipment which is minor in character, from 1849 to the present time, with the reasons for retirement for those facilities which have been retired.

Causes of Retirement

With minor exceptions records were not kept of, nor was it possible to determine, the causes of retirement of mains, meters and hydrants. Neither was it determinable whether such facilities were abandoned or whether there was salvage and re-use of certain units.

Acknowledgments

The collection and compilation of the data in Utica were done by and under the direction of J. Walter Ackerman, a member of the Committee on Survival and Retirement Experience With Water Works Facilities, with the co-operation of the Utica Board of Water Supply of which H. B. Miles is General Manager.

Summary of Class B Facilities

Utica, New York

Impounding Reservoirs

Tracy Reservoir—Ambursen concrete dam on Black Creek, approximately 345 ft. long, impounding 1,200 mil.gal. from a watershed area of 25.3 sq.mi. Constructed in 1906–1907 and still in service.

Hinckley Reservoir—Constructed by the state for State Barge Canal regulation, from which the city has the right to draw 50 mgd., provided the storage available in Tracy Reservoir is used for compensation to provide a certain minimum amount for the Barge Canal. Reservoir of 25,000-mil.gal. capacity is formed by an earthen dam with concrete spillway on West Canada Creek; drainage area 400 sq.mi. Dam 3,700 ft. long with 400-ft. spillway; maximum height 93 ft. from bottom to top of core wall. Constructed in 1912 and still in service.

Distribution Reservoirs

No. 1—Graefenberg Reservoir—Earth embankment dam, 28-mil.gal. capacity; maximum depth 50 ft.; area about seven acres. Originally constructed in 1854, raised 6 ft. in 1864–1865 and still in service.

No. 2—Hopper Storage Reservoir—Earth embankment, puddled core wall; 36-mil.gal. capacity; area about 12.6 acres. Originally constructed in 1868, enlarged and deepened in 1886 and still in service.

No. 3—Earth embankment reservoir, 228-mil.gal. capacity, maximum depth 59 ft.; area about 26 acres. Constructed in 1873 and retired in 1902 because of failure of embankment.

No. 4—Golden Reservoir—Earth embankment reservoir, capacity 282 mil.gal.; puddled core wall; average depth 24 ft.; area 34 acres. Constructed in 1886, raised 10 ft. in 1896 and still in service.

No. 5—Cascade Reservoir—Earth embankment reservoir, capacity 187 mil.gal.; puddled core; average depth 24 ft.; area 23 acres. Constructed in 1896, reinforced in 1902, and still in service.

No. 6—Bacot Reservoir—Earth embankment reservoir, capacity 98 mil.gal.; puddled core; maximum depth 43 ft.; area 14 acres. Constructed in 1900, embankment reinforced in 1903, and still in service.

No. 7—Bacot Forebay—Earth embankment dam, capacity 6.5 mil.gal.; puddled core; maximum depth 15 ft.; area 1.7 acres. Constructed in 1900, and still in service.

No. 8—New Hartford Reservoir—Earth embankment reservoir, capacity 1.5 mil.gal.; maximum depth 8 ft.; area 1.4 acres. Constructed in 1895 and still in service.

No. 9—Earth embankment reservoir, capacity 2.5 mil.gal.; maximum depth 10 ft.; area 1.2 acres. Constructed in 1895 and abandoned in 1925 due to diminishing supply and increasing pollution.

No. 10—Whites Town Reservoir—Earth embankment reservoir, capacity 3.5 mil.gal.; area 1.7 acres. Constructed in 1898; not in use but held in reserve.

No. 11—Marcy Reservoir—Earth embankment reservoir, capacity 15 mil.gal.; concrete cut-off wall; maximum depth 30 ft.; area 3.5 acres. Constructed in 1913, and still in service.

Original Reservoir—Unknown construction and size. Constructed in 1849 and abandoned in 1868 because of low pressure due to low elevation.

Elevated Tanks and Standpipes

Old Oriskany Standpipe—Open steel standpipe, 30 ft. in diameter, 50 ft. high; 250,000-gal. capacity. Constructed in 1916–1917 and still in service.

New Oriskany Standpipe—Open steel standpipe, 26 ft. in diameter, 50 ft. high; 200,000-gal. capacity. Constructed in 1934 and still in service.

Whites Town Standpipe—Open steel standpipe, 29 ft. in diameter, 49 ft. high; 250,000-gal. capacity. Constructed in 1935 and still in service.

New Hartford Elevated Tank—Covered steel elevated tank, hemispherical bottom; 32 ft. in diameter, 47 ft. deep, 99 ft. to flow line; 250,000-gal. capacity. Constructed in 1928 and still in service.

South Hill Standpipe—Covered steel standpipe, 48 ft. in diameter, 19 ft. high; 266,000-gal. capacity. Constructed in 1928 and still in service.

Old New Hartford Elevated Tank—Covered steel elevated tank, hemispherical bottom; 19 ft. in diameter, 17½ ft. deep; 50,000-gal. capacity. Constructed in 1916 and retired in 1928 because it was below required pressure and small size.

Summary of Installations and Retirements
Utica, New York

Mains

3-in. Cast-Iron Unlined Mains

Year	*Feet*			*Year*	*Feet*		
Installed	*Installed*	*In Service*	*Retired*	*Installed*	*Installed*	*In Service*	*Retired*
1849	10,260	0	10,260	1869	5,934	2,519	3,415
1850	2,658	0	2,658	1871	900	900	0
1851	1,534	0	1,534	1872	390	0	390
1852	271	0	271	1875	406	36	370
1853	1,430	0	1,430	1886	100	0	100
1854	240	0	240	1888	135	135	0
1859	100	0	100	1889	195	195	0
1860	151	116	35	1894	379	379	0
1861	150	110	40	1896	170	170	0
1863	372	0	372	1898	12	0	12
1864	72	0	72	1901	70	70	0
1866	20	0	20	1940	0	0	0
1867	440	0	440				
1868	1,163	290	873	Total	27,552	4,920	22,632

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*	*Year Installed*	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1849	410	1868	2,390	1887	275	1889	1861	40	1929				
	1,770	1890	240	1892	1,230	1893	1863	130	1907	122	1908	120	1929
	900	1894	3,045	1896			1864	72	1893				
1850	115	1887	662	1889	350	1892	1866	20	1892				
	275	1893	491	1895	241	1897	1867	440	1907				
	222	1899	142	1910	160	1914	1868	150	1874	176	1888	139	1892
1851	307	1887	175	1890	298	1894		108	1910	58	1913	242	1929
	188	1897	265	1905	301	1917	1869	940	1887	460	1890	12	1907
1852	271	1889						1,153	1914	642	1915	52	1919
1853	200	1857	500	1871	140	1889		97	1929	34	1934	25	1938
	420	1892	170	1913			1872	390	1907				
1854	240	1893					1875	370	1917				
1859	100	1888					1886	100	1914				
1860	35	1890					1898	12	1910				

4-in. Cast-Iron Unlined Mains

Year	*Feet*			*Year*	*Feet*		
Installed	*Installed*	*In Service*	*Retired*	*Installed*	*Installed*	*In Service*	*Retired*
1849	6,250	1,564	4,686	1862	109	0	109
1850	3,605	0	3,605	1863	176	176	0
1853	3,612	1,688	1,924	1867	487	420	67
1858	368	287	81	1868	7,995	2,310	5,685
1860	490	240	250	1869	8,500	4,533	3,967

4-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet: Installed	Feet: In Service	Feet: Retired	Year Installed	Feet: Installed	Feet: In Service	Feet: Retired
1871	1,411	1,018	393	1894	526	437	89
1872	984	977	7	1895	58	58	0
1873	2,207	376	1,831	1896	171	171	0
1874	3,274	1,482	1,792	1897	444	420	24
1875	2,835	1,662	1,173	1899	16	0	16
1876	224	24	200	1900	32	32	0
1877	175	175	0	1901	25	25	0
1878	950	850	100	1904	130	130	0
1879	365	365	0	1906	22	22	0
1880	483	233	250	1908	535	535	0
1881	798	798	0	1910	522	522	0
1882	60	0	60	1912	41	41	0
1884	375	315	60	1914	11	0	11
1885	714	297	417	1915	350	350	0
1886	589	83	506	1926	156	156	0
1887	1,904	1,137	767	1928	23	13	10
1888	4,225	2,016	2,209	1930	16	16	0
1889	238	23	215	1934	20	20	0
1890	1,111	137	974	1940	0	0	0
1891	3,036	2,794	242				
1892	955	890	65	Total	63,045	30,420	32,625
1893	1,442	602	840				

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1849	1,160	1893	375	1895	257	1898	1876	200	1910				
	1,195	1901	48	1907	65	1908	1878	100	1886				
	18	1910	42	1912	1,462	1917	1880	250	1894				
	64	1919					1882	60	1916				
1850	800	1887	175	1895	1,580	1905	1884	60	1899				
	1,050	1908					1885	264	1907	153	1913		
1853	1,000	1897	575	1899	50	1905	1886	382	1907	124	1915		
	100	1907	41	1912	100	1918	1887	315	1908	117	1909	25	1915
	58	1919						310	1917				
1858	81	1907					1888	548	1908	12	1909	1,290	1911
1860	250	1868						99	1913	260	1914		
1862	109	1907					1889	170	1908	35	1913	10	1915
1867	67	1907					1890	32	1908	703	1909	94	1913
1868	1,036	1886	560	1889	444	1896		95	1914	50	1915		
	605	1907	1,460	1908	1,580	1915	1891	76	1905	66	1907	100	1908
1869	955	1887	165	1895	891	1904	1892	65	1908				
	380	1908	39	1911	1,070	1913	1893	505	1907	335	1911		
	339	1914	128	1922			1894	41	1913	38	1915	10	1929
1871	245	1907	148	1913			1897	24	1908				
1872	7	1913					1899	16	1912				
1873	200	1894	570	1907	1,061	1908	1914	11	1915				
1874	340	1907	740	1912	712	1916	1928	10	1930				
1875	308	1912	27	1914	838	1916							

6-in. Cast-Iron Unlined Mains

Year	Feet			Year	Feet		
Installed	Installed	In Service	Retired	Installed	Installed	In Service	Retired
1849	4,780	3,299	1,481	1905	11,772	11,772	0
1853	1,790	1,790	0	1906	8,349	8,166	183
1860	37	37	0	1907	6,348	6,348	0
1868	16,017	14,435	1,582	1908	6,958	6,958	0
1869	7,642	7,642	0	1909	1,711	1,711	0
1870	3,805	3,805	0	1910	5,932	5,850	82
1871	8,540	8,540	0	1911	11,155	11,155	0
1873	2,407	2,112	295	1912	5,685	5,425	260
1874	14,606	14,606	0	1913	7,985	7,581	404
1875	362	350	12	1914	16,039	16,039	0
1878	49	36	13	1915	8,997	8,997	0
1879	1,200	1,200	0	1916	8,353	8,353	0
1880	973	973	0	1917	4,162	3,910	252
1881	961	941	20	1918	722	722	0
1882	47	47	0	1919	13,292	13,292	0
1884	320	320	0	1920	1,629	1,629	0
1885	6,133	6,105	28	1921	23,683	23,558	125
1886	22,024	21,927	97	1922	25,827	25,817	10
1887	16,956	16,916	40	1923	28,249	27,376	873
1888	25,122	25,086	36	1924	12,691	12,691	0
1889	19,351	19,111	240	1925	13,884	13,884	0
1890	19,655	19,556	99	1926	7,200	6,988	212
1891	16,595	16,595	0	1927	17,000	16,458	542
1892	14,988	14,988	0	1928	7,763	7,723	40
1893	15,282	13,598	1,684	1929	7,453	7,371	82
1894	13,721	13,142	579	1930	7,122	7,122	0
1895	15,592	14,948	644	1931	6,193	6,183	10
1896	6,083	5,813	270	1932	1,622	1,614	8
1897	11,674	11,654	20	1933	1,355	1,355	0
1898	7,409	7,409	0	1934	483	483	0
1899	7,598	7,382	216	1935	162	162	0
1900	7,263	7,263	0	1937	55	55	0
1901	7,840	7,344	496	1938	18	18	0
1902	6,766	6,766	0	1940	0	0	0
1903	4,195	4,195	0				
1904	9,174	9,137	37	Total	596,806	585,834	10,972

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1849	1,115	1896	105	1912	261	1937	1893	1,684	1908				
1868	1,020	1870	342	1915	220	1922	1894	579	1908				
1873	295	1908					1895	128	1913	84	1916	432	1923
1875	12	1908					1896	270	1910				
1878	13	1908					1897	20	1911				
1881	20	1913					1899	216	1931				
1885	28	1908					1901	496	1935				
1886	48	1912	49	1913			1904	37	1929				
1887	40	1912					1906	183	1935				
1888	14	1911	22	1913			1910	60	1929	22	1937		
1889	62	1913	70	1923	108	1937	1912	260	1924				
1890	75	1908	24	1913			1914	404	1931				

6-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1917	252	1934					1927	542	1934				
1921	15	1934	110	1938			1928	10	1930	30	1934		
1922	10	1933					1929	16	1934	66	1937		
1923	870	1934	3	1939			1931	10	1940				
1926	212	1934					1932	8	1939				

8-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired	Year Installed	Feet Installed	Feet In Service	Feet Retired
1849	3,060	1,578	1,482	1910	623	623	0
1868	1,813	1,337	476	1911	2,881	2,881	0
1874	2,560	2,560	0	1912	3,223	3,223	0
1875	4,073	4,051	22	1913	7,835	7,561	274
1878	1,680	1,680	0	1914	3,313	3,313	0
1881	1,841	1,841	0	1915	2,160	2,160	0
1882	5,910	5,513	397	1916	2,106	2,106	0
1885	190	190	0	1917	4,845	4,845	0
1886	7,421	7,392	29	1919	391	391	0
1887	12,063	12,063	0	1920	206	206	0
1888	3,225	3,199	26	1921	24	24	0
1889	2,902	2,902	0	1922	1,279	1,279	0
1891	15	15	0	1923	6,844	6,832	12
1892	1,721	1,721	0	1924	4,660	4,660	0
1893	4,697	4,697	0	1925	2,438	2,438	0
1894	1,572	1,572	0	1926	2,707	2,250	457
1895	1,692	1,692	0	1927	1,391	1,391	0
1896	3,782	3,782	0	1929	2,889	2,889	0
1897	1,240	1,240	0	1930	67	67	0
1898	1,981	1,981	0	1931	1,653	1,653	0
1900	1,227	1,227	0	1932	603	603	0
1901	620	620	0	1933	550	550	0
1903	1,268	1,268	0	1934	102	102	0
1904	2,047	2,047	0	1938	22	22	0
1905	1,024	1,024	0	1939	117	117	0
1906	1,908	1,908	0	1940	0	0	0
1907	7,311	7,311	0				
1908	3,855	3,855	0	TOTAL	135,949	132,774	3,175
1909	322	322	0				

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1849	200	1894	1,141	1915	15	1923	1886	29	1935				
	126	1940					1888	26	1931				
1868	476	1913					1913	274	1925				
1875	22	1908					1923	12	1940				
1882	397	1931					1926	457	1934				

10-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1849	4,630	4,050	580
1868	3,050	3,050	0
1869	1,020	535	485
1880	2,080	2,080	0
1885	2,425	2,425	0
1887	1,845	1,845	0
1892	2,996	2,055	941
1894	485	485	0
1900	3,802	3,802	0
1901	1,790	1,790	0
1905	8,050	7,867	183
1907	949	949	0
1908	2,238	2,028	210
1909	8	8	0
1910	324	324	0
1911	341	341	0
1912	627	627	0
1913	38	38	0
1915	31	31	0
1916	1,021	1,021	0
1940	23	23	0
Total	37,773	35,374	2,399

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1849	580	1934		
1869	485	1894		
1892	841	1905	100	1916
1905	183	1916		
1908	210	1915		

12-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1849	300	300	0
1853	300	300	0
1868	3,130	2,394	736
1870	5,522	5,411	111
1871	3,402	3,402	0
1886	2,325	2,325	0
1887	500	500	0
1891	23	23	0
1897	500	500	0
1900	5,011	5,011	0
1905	2,671	2,671	0
1906	5,833	5,833	0
1907	75	75	0
1908	9,868	9,868	0
1909	797	797	0
1913	2,721	2,721	0
1914	297	297	0
1915	2,582	2,582	0
1916	1,087	1,087	0
1917	1,066	1,066	0
1918	259	259	0
1919	99	99	0
1921	5,161	5,161	0
1923	2,213	2,213	0
1924	2,980	2,980	0
1925	1,825	1,825	0
1926	3,363	3,363	0
1927	6,814	6,814	0
1928	11,283	11,283	0
1929	1,347	1,347	0
1930	56	56	0
1931	230	230	0
1932	207	207	0
1933	529	529	0
1934	896	896	0
1935	44	44	0
1938	7,361	7,361	0
1940	934	934	0
Total	93,611	92,764	847

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1868	442	1916	294	1928
1870	111	1909		

16-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1886	795	795	0
1898	854	854	0
1901	412	412	0
1904	22,766	22,766	0
1905	1,954	1,954	0
1906	27	27	0
1907	53	53	0
1908	3,512	3,512	0
1909	155	155	0
1913	1,133	1,133	0
1921	38	38	0
1929	280	280	0
1940	0	0	0
Total	31,979	31,979	0

20-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1885	6,541	6,541	0
1886	8,438	8,438	0
1900	16,704	15,586	1,118
1905	215	0	215
1907	19,977	19,977	0
1913	1,937	1,937	0
1915	651	651	0
1916	253	215	38
1921	27	27	0
1924	33	33	0
1940	0	0	0
Total	54,776	53,405	1,371

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1900	193	1905	404	1913	355	1915
	166	1916				
1905	215	1916				
1916	38	1918				

24-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1885	6,924	6,814	110
1906	62,845	62,845	0

24-in. Cast-Iron Unlined Mains (contd.)

Year	Feet		
Installed	Installed	In Service	Retired
1912	596	596	0
1913	28,555	28,479	76
1915	266	266	0
1916	70	70	0
1921	54	54	0
1924	13,384	13,384	0
1940	0	0	0
Total	112,694	112,508	186

Retirements by Years

Year Installed	Feet	Year
1885	110	1916
1913	76	1921

30-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1924	5,615	5,615	0
1940	0	0	0
Total	5,615	5,615	0

6-in. Cast-Iron Cement-Lined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1934	1,877	1,877	0
1935	443	443	0
1936	1,750	1,750	0
1937	1,332	1,332	0
1938	40	40	0
1939	586	586	0
1940	41	41	0
Total	5,069	5,069	0

8-in. Cast-Iron Cement-Lined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1938	26	26	0
1940	0	0	0
Total	26	26	0

12-in. Cast-Iron Cement-Lined Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1934	651	651	0
1935	565	565	0
1940	0	0	0
Total	1,216	1,216	0

21-in. Steel Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1934	128	128	0
1940	0	0	0
Total	128	128	0

⅝-in. Lead Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1913	28	28	0
1940	0	0	0
Total	28	28	0

¾-in. Lead Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1898	45	45	0
1899	103	103	0
1940	0	0	0
Total	148	148	0

¾-in. Wrought-Iron Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1913	63	63	0
1940	0	0	0
Total	63	63	0

1-in. Wrought-Iron Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1891	33	33	0
1909	138	0	138
1919	150	0	150
1923	65	0	65

1-in. Wrought-Iron Mains (contd.)

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1924	56	0	56
1940	0	0	0
Total	442	33	409

Retirements by Years

Year Installed	*Feet*	*Year*
1909	138	1915
1919	150	1932
1923	65	1932
1924	56	1932

1½-in. Wrought-Iron Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1860	126	0	126
1902	235	0	235
1908	849	0	849
1940	0	0	0
Total	1,210	0	1,210

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*
1860	126	1899		
1902	235	1902		
1908	424	1917	425	1921

2-in. Wrought-Iron Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1851	175	0	175
1908	1,064	0	1,064
1910	433	433	0
1926	10	10	0
1928	20	20	0
1940	0	0	0
Subtotal	1,702	463	1,239
Unknown	54	0	54
Total	1,756	463	1,293

Retirements by Years

Year Installed	*Feet*	*Year*
1851	175	1890
1908	1,064	1917

2½-in. Wrought-Iron Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1902	2,863	0	2,863
1909	14	0	14
1940	0	0	0
Total	2,877	0	2,877

Retirements by Years

Year Installed	Feet	Year
1902	2,863	1917
1909	14	1917

¾-in. Copper Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1935	31	31	0
1940	0	0	0
Total	31	31	0

1-in. Copper Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1935	226	226	0
1940	0	0	0
Total	226	226	0

1½-in. Copper Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1935	158	158	0
1940	0	0	0
Total	158	158	0

2-in. Copper Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1938	4	4	0
1940	0	0	0
Total	4	4	0

1-in. Galvanized Steel Lead-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1913	98	98	0
1940	0	0	0
Total	98	98	0

2-in. Galvanized Steel Lead-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1913	128	128	0
1940	0	0	0
Total	128	128	0

6-in. Steel Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1940	470	470	0
Total	470	470	0

8-in. Steel Bituminous-Lined and Coated Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1937	45	45	0
1940	0	0	0
Total	45	45	0

METERS

$\frac{5}{8}$-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1890	1	1	0
1891	1	0	1
1895	6	5	1
1896	105	13	92
1897	134	46	88
1898	184	70	114
1899	195	125	70
1900	26	13	13
1901	34	22	12
1902	391	143	248
1903	369	125	244
1904	708	702	6
1905	540	538	2
1906	761	760	1
1907	536	535	1
1908	411	410	1
1909	614	614	0
1910	758	722	36
1911	482	460	22
1912	414	391	23
1913	661	587	74
1914	659	658	1
1915	540	540	0
1916	571	571	0
1917	535	534	1
1918	439	439	0
1919	411	411	0
1920	505	505	0
1921	522	521	1
1922	755	754	1
1923	1,307	1,306	1
1924	1,073	1,073	0
1925	748	748	0
1926	1,307	1,307	0
1927	222	222	0
1928	186	186	0
1929	20	20	0
1930	139	139	0
1931	159	159	0
1932	66	66	0
1933	2	2	0
1934	193	193	0
1936	23	22	1
1937	133	133	0
1938	139	139	0
1939	169	169	0
1940	65	65	0
TOTAL	18,219	17,164	1,055

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1891	1	1935				
1895	1	1937				
1896	1	1928	5	1934	1	1935
	5	1936	13	1937	7	1938
	36	1939	24	1940		
1897	1	1929	1	1930	1	1931
	1	1932	1	1933	1	1934
	1	1935	5	1936	22	1937
	10	1938	25	1939	19	1940
1898	1	1930	2	1931	2	1933
	3	1934	4	1936	28	1937
	16	1938	37	1939	21	1940
1899	1	1931	9	1934	1	1935
	2	1936	16	1937	10	1938
	19	1939	12	1940		
1900	1	1934	1	1936	2	1937
	2	1938	6	1939	1	1940
1901	1	1934	1	1936	1	1937
	3	1938	3	1939	3	1940
1902	2	1928	2	1929	2	1931
	2	1932	9	1934	3	1935
	8	1936	59	1937	32	1938
	86	1939	43	1940		
1903	1	1928	2	1929	2	1930
	6	1931	4	1933	15	1934
	7	1935	9	1936	57	1937
	20	1938	80	1939	41	1940
1904	1	1938	5	1939		
1905	1	1929	1	1937		
1906	1	1934				
1907	1	1940				
1908	1	1938				
1910	1	1931	2	1934	1	1935
	2	1936	12	1937	1	1938
	10	1939	7	1940		
1911	1	1934	2	1936	5	1937
	3	1938	7	1939	4	1940
1912	1	1934	9	1937	1	1938
	9	1939	3	1940		
1913	1	1934	2	1936	22	1937
	6	1938	30	1939	13	1940
1914	1	1937				
1917	1	1932				
1921	1	1940				
1922	1	1937				
1923	1	1939				
1936	1	1937				

¾-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired	Year Installed	Number Installed	Number In Service	Number Retired
1903	3	3	0	1916	15	15	0
1904	20	20	0	1917	81	81	0
1905	8	8	0	1918	5	5	0
1906	53	53	0	1919	8	8	0
1907	5	5	0	1920	16	16	0
1908	27	27	0	1926	36	36	0
1909	14	14	0	1929	11	11	0
1912	45	45	0	1933	2	2	0
1913	44	44	0	1940	0	0	0
1914	24	24	0				
1915	5	5	0	Total	422	422	0

1-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired	Year Installed	Number Installed	Number In Service	Number Retired
1899	1	1	0	1918	23	23	0
1903	1	1	0	1923	12	12	0
1904	10	10	0	1924	7	7	0
1905	8	8	0	1925	7	7	0
1906	14	14	0	1926	15	15	0
1908	5	5	0	1927	12	12	0
1909	8	8	0	1929	12	12	0
1910	5	5	0	1930	8	8	0
1911	14	14	0	1931	7	7	0
1912	26	26	0	1933	4	4	0
1913	15	15	0	1940	0	0	0
1914	5	5	0				
1915	5	5	0	Total	237	237	0
1916	13	13	0				

1½-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired	Year Installed	Number Installed	Number In Service	Number Retired
1906	5	5	0	1928	1	1	0
1908	1	1	0	1929	1	1	0
1909	4	4	0	1940	0	0	0
1925	3	3	0				
1926	2	2	0	Total	19	19	0
1927	2	2	0				

2-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired	Year Installed	Number Installed	Number In Service	Number Retired
1906	7	7	0	1927	1	1	0
1907	5	5	0	1928	4	4	0
1908	12	12	0	1929	1	1	0
1909	6	6	0	1930	6	6	0
1910	2	2	0	1931	3	3	0
1924	1	1	0	1940	0	0	0
1925	6	6	0				
1926	2	2	0	Total	56	56	0

1½-IN. COMPOUND METERS

Year Installed	*Number Installed*	*In Service*	*Retired*
1912	1	1	0
1913	4	4	0
1914	3	3	0
1915	7	7	0
1916	3	3	0
1917	2	2	0
1918	3	3	0
1919	1	1	0
1921	2	2	0
1922	4	4	0
1923	4	4	0
1924	4	4	0
1925	4	4	0
1926	2	2	0
1927	1	1	0
1928	3	3	0
1929	2	2	0
1933	1	1	0
1940	0	0	0
TOTAL	51	51	0

2-IN. COMPOUND METERS

Year Installed	*Number Installed*	*In Service*	*Retired*
1911	7	7	0
1912	14	14	0
1913	4	4	0
1914	3	3	0
1915	8	8	0
1916	7	7	0
1917	2	2	0
1918	4	4	0
1919	4	4	0
1920	1	1	0
1921	6	6	0
1922	8	8	0
1923	10	10	0
1924	10	10	0
1925	7	7	0
1926	8	8	0
1927	3	3	0
1928	2	2	0
1929	4	4	0
1940	0	0	0
TOTAL	112	112	0

3-IN. COMPOUND METERS

Year Installed	*Number Installed*	*In Service*	*Retired*
1910	4	4	0
1911	2	2	0
1912	3	3	0
1913	2	2	0
1915	2	2	0
1916	6	6	0
1917	1	1	0
1918	1	1	0
1920	1	1	0
1921	1	1	0
1922	1	1	0
1923	5	5	0
1925	1	1	0
1926	1	1	0
1929	1	1	0
1932	1	1	0
1934	1	1	0
1940	1	1	0
TOTAL	35	35	0

4-IN. COMPOUND METERS

Year Installed	*Number Installed*	*In Service*	*Retired*
1910	1	1	0
1911	1	1	0
1912	7	7	0
1913	6	6	0
1914	2	2	0
1916	3	3	0
1917	3	3	0
1918	1	1	0
1920	3	3	0
1921	1	1	0
1922	3	3	0
1923	2	2	0
1924	2	2	0
1925	3	3	0
1926	1	1	0
1928	3	3	0
1929	3	3	0
1930	1	1	0
1933	1	1	0
1937	1	1	0
1940	0	0	0
TOTAL	48	48	0

6-in. Compound Meters

Year Installed	Number Installed	Number In Service	Number Retired
1916	1	1	0
1917	2	2	0
1918	4	4	0
1919	1	1	0
1920	1	1	0
1921	1	1	0
1922	1	1	0
1924	3	3	0
1925	2	2	0
1926	2	2	0
1927	2	2	0
1928	1	1	0
1929	1	1	0
1930	1	1	0
1932	1	1	0
1933	1	1	0
1937	1	1	0
1938	2	2	0
1940	0	0	0
Total	28	28	0

8-in. Compound Meters

Year Installed	Number Installed	Number In Service	Number Retired
1917	1	1	0
1926	4	4	0
1927	1	1	0
1928	1	1	0
1933	1	1	0
1940	0	0	0
Total	8	8	0

3-in. Crest Meters

Year Installed	Number Installed	Number In Service	Number Retired
1906	2	2	0
1908	1	1	0
1909	1	1	0
1940	0	0	0
Total	4	4	0

4-in. Crest Meters

Year Installed	Number Installed	Number In Service	Number Retired
1904	1	1	0
1906	4	4	0
1940	0	0	0
Total	5	5	0

3-in. Current Meters

Year Installed	Number Installed	Number In Service	Number Retired
1904	4	4	0
1940	0	0	0
Total	4	4	0

4-in. Current Meters

Year Installed	Number Installed	Number In Service	Number Retired
1906	1	1	0
1912	1	1	0
1940	0	0	0
Total	2	2	0

6-in. Current Meters

Year Installed	Number Installed	Number In Service	Number Retired
1906	1	1	0
1940	0	0	0
Total	1	1	0

$\frac{5}{8}$-in. Piston Meters

Year Installed	Number Installed	Number In Service	Number Retired
1890	1	1	0
1891	79	32	47
1892	123	42	81
1893	140	62	78
1894	156	57	99
1895	36	2	34
1896	278	105	173
1897	180	68	112
1898	107	41	66
1899	115	43	72
1900	347	138	209
1901	438	182	256
1902	90	40	50
1903	145	61	84
1904	22	5	17
1909	1	1	0
1919	1	1	0
1936	1	1	0
1937	317	317	0
1938	83	83	0
1940	0	0	0
Total	2,660	1,282	1,378

$\frac{5}{8}$-in. Piston Meters (contd.)

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1891	12	1937	7	1938	13	1939
	15	1940				
1892	1	1935	14	1937	8	1938
	23	1939	35	1940		
1893	1	1934	16	1937	14	1938
	19	1939	28	1940		
1894	18	1937	19	1938	24	1939
	38	1940				
1895	9	1937	6	1938	6	1939
	13	1940				
1896	1	1933	27	1937	40	1938
	35	1939	70	1940		
1897	1	1935	1	1936	27	1937
	16	1938	39	1939	28	1940
1898	13	1937	16	1938	15	1939
	22	1940				
1899	1	1936	19	1937	9	1938
	20	1939	23	1940		
1900	50	1937	48	1938	40	1939
	71	1940				
1901	60	1937	36	1938	51	1939
	109	1940				
1902	1	1935	7	1937	10	1938
	16	1939	16	1940		
1903	21	1937	14	1938	20	1939
	29	1940				
1904	4	1937	2	1938	6	1939
	5	1940				

3-in. Piston Meters

Year Installed	Number Installed	In Service	Retired
1897	1	1	0
1900	1	1	0
1940	0	0	0
Total	2	2	0

4-in. Protectus Meters

Year Installed	Number Installed	In Service	Retired
1918	1	1	0
1919	2	2	0
1921	1	1	0
1922	1	1	0
1940	0	0	0
Total	5	5	0

6-in. Protectus Meters

Year Installed	Number Installed	In Service	Retired
1916	1	1	0
1918	2	2	0
1919	17	17	0
1920	7	7	0
1921	1	1	0
1923	4	4	0
1924	2	2	0
1925	1	1	0
1926	1	1	0
1940	0	0	0
Total	36	36	0

8-in. Protectus Meters

Year Installed	Number Installed	In Service	Retired
1919	15	15	0
1920	1	1	0
1922	5	5	0
1923	1	1	0
1924	2	2	0
1940	0	0	0
Total	24	24	0

6-in. Detector Meters

Year Installed	Number Installed	In Service	Retired
1913	1	1	0
1924	1	1	0
1931	1	1	0
1940	0	0	0
Total	3	3	0

4- × 1-in. Valve Meters

Year Installed	Number Installed	In Service	Retired
1897	1	1	0
1912	1	1	0
1927	1	1	0
1928	1	1	0
1929	4	4	0
1940	0	0	0
Total	8	8	0

6- × 1-in. Valve Meters

Year Installed	Number Installed	Number In Service	Number Retired
1912	1	1	0
1925	1	1	0
1940	0	0	0
Total	2	2	0

6- × 1½-in. Valve Meters

Year Installed	Number Installed	Number In Service	Number Retired
1925	3	3	0
1926	7	7	0
1927	4	4	0
1928	7	7	0
1929	5	5	0
1930	3	3	0
1931	4	4	0

6- × 1½-in. Valve Meters (contd.)

Year Installed	Number Installed	Number In Service	Number Retired
1932	2	2	0
1933	2	2	0
1940	0	0	0
Total	37	37	0

6- × 2-in. Valve Meters

Year Installed	Number Installed	Number In Service	Number Retired
1908	1	1	0
1924	1	1	0
1925	2	2	0
1940	0	0	0
Total	4	4	0

Hydrants

3- to 10-in. Hydrants

Year Installed	Number Installed	Number In Service	Number Retired
1849	8	5	3
1853	2	2	0
1860	1	0	1
1868	10	7	3
1869	29	22	7
1870	7	4	3
1871	17	12	5
1873	5	3	2
1874	23	20	3
1875	7	7	0
1876	1	0	1
1877	1	0	1
1879	1	0	1
1881	8	6	2
1882	6	4	2
1884	1	1	0
1885	23	17	6
1886	50	45	5
1887	50	36	14
1888	34	23	11
1889	24	19	5
1890	20	18	2
1891	18	16	2
1892	17	12	5
1893	12	10	2
1894	8	7	1
1895	17	14	3
1896	21	15	6
1897	34	29	5
1898	85	77	8
1899	52	47	5
1900	46	42	4
1901	30	27	3
1902	25	23	2
1903	17	17	0
1904	27	27	0
1905	37	35	2
1906	15	14	1
1907	73	62	11
1908	43	39	4
1909	4	4	0
1910	13	13	0
1911	19	18	1
1912	16	14	2
1913	37	35	2
1914	38	37	1
1915	31	30	1
1916	22	22	0
1917	17	17	0
1918	7	6	1
1919	29	29	0
1920	10	10	0
1921	54	54	0
1922	68	68	0
1923	77	77	0
1924	58	58	0

3- TO 10-IN. HYDRANTS (contd.)

Year Installed	Number Installed	Number In Service	Number Retired
1925	48	48	0
1926	28	28	0
1927	41	41	0
1928	31	31	0
1929	35	34	1
1930	27	27	0
1931	26	26	0
1932	6	6	0
1933	6	6	0
1934	20	20	0
1935	9	9	0
1936	9	9	0
1937	10	10	0
1938	10	10	0
1939	5	5	0
1940	10	10	0
TOTAL	1,726	1,576	150

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1849	1	1911	1	1924	1	1940
1860	1	1938				
1868	1	1923	1	1932	1	1934
1869	1	1908	1	1909	1	1924
	1	1929	1	1932	1	1934
	1	1937				
1870	1	1925	1	1928	1	1931
1871	1	1921	1	1923	1	1925
1873	1	1924	1	1933		
1874	1	1930	1	1931	1	1940
1876	1	1930				
1877	1	1929				
1879	1	1938				
1881	1	1930	1	1936		
1882	1	1929	1	1937		
1885	2	1924	1	1931	1	1936
	2	1940				
1886	1	1915	1	1923	1	1928
	1	1930	1	1939		
1887	1	1912	1	1919	2	1925
	1	1928	1	1929	1	1930
	3	1934	1	1937	2	1938
	1	1939				
1888	1	1924	2	1926	1	1928
	2	1930	2	1931	1	1939
	2	1940				
1889	1	1925	1	1926	1	1930
	1	1933	1	1934		
1890	1	1922	1	1933		
1891	1	1925	1	1927		
1892	1	1928	1	1931	1	1934
	1	1937	1	1938		
1893	1	1925	1	1936		
1894	1	1939				
1895	1	1907	1	1924	1	1933
1896	1	1923	1	1930	2	1931
	1	1937	1	1938		
1897	1	1918	1	1924	1	1931
	1	1935	1	1938		
1898	1	1922	1	1925	2	1929
	1	1931	1	1932	1	1933
	1	1936				
1899	1	1921	1	1922	1	1932
	1	1934	1	1940		
1900	2	1934	2	1940		
1901	1	1920	1	1922	1	1926
1902	1	1920	1	1928		
1905	1	1925	1	1929		
1906	1	1940				
1907	1	1921	1	1923	2	1924
	2	1929	1	1930	1	1931
	2	1936	1	1939		
1908	1	1922	1	1923	1	1931
	1	1935				
1911	1	1938				
1912	1	1922	1	1923		
1913	1	1913	1	1931		
1914	1	1924				
1915	1	1924				
1918	1	1937				
1929	1	1935				

Clinton, Iowa—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1939

THE privately-owned Clinton Water Works Company is a subsidiary of the American Water Works & Electric Company, Inc., serving the city of Clinton, Iowa, and a small area outside the city limits.

The city of Clinton, the county seat of Clinton County, is situated in the east central part of Iowa on the Mississippi River about 130 mi. west of Chicago. It was first settled in 1855 and incorporated as a village in 1857. At the time of the original construction of the Clinton Water Works, in 1874–1875, the population was 7,500. From that time until 1910 Clinton experienced a fairly steady growth, but since 1910 there has been little increase in population. The 1940 census gave the population of the city as 26,270.

Clinton was originally a lumber manufacturing center of considerable importance and had at one time what was considered the largest saw mill in the world. With the decline of the logging business on the Mississippi River the town suffered considerably, but there has been gradually built up some industrial activity of a diversified nature. The Du Pont Company has recently built a large cellophane plant on the outskirts of the city.

The territory served is therefore both residential and industrial. As of Dec. 31, 1939, there were 6,638 consumers, 91.9 per cent of whom were served through meter measurement. There were in the system about 75 mi. of mains with 576 hydrants. The average daily pumpage during 1939 was 2.57 mil.gal. of which about 64.5 per cent was measured through consumers' meters. This pumpage is equivalent to about 99 gpd. per capita.

Development of Existing System

The original Clinton Water Works franchise was granted in 1874 and the system was built during 1874–1875. Under this franchise the company was granted the right to construct and maintain its pumping station and to develop the water supply in the public park on the river front where it has since been maintained.

The original supply was taken from the Mississippi River and filtered through boxes filled with sand which were placed in the bottom of a rectangular well 53 ft. long, 12 ft. 6 in. wide and 25 ft. deep, divided by a central wall. From the well the water flowed through a tunnel into a suction well. There is no definite record of how long this method was used.

In 1886 two artesian wells were installed and when a new contract was made in 1889 the use of Mississippi water as a regular source of supply was abandoned and wells at or adjacent to the pumping station have since that time formed the source of supply.

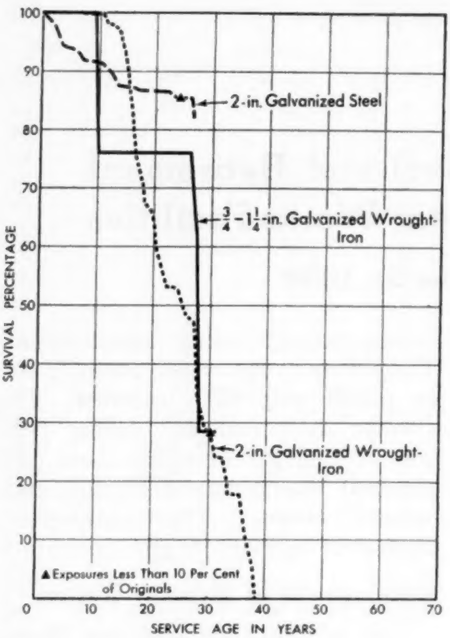


FIG. 1. Mortality Survival Curve—$\frac{3}{4}$–2-in. Galvanized Wrought-Iron and Galvanized Steel Mains—Clinton, Iowa

BASE: Feet SURVIVAL: 1890–1939

SIZE *in.*	KIND	EXPOSURES *ft.*	RETIREMENTS *ft.*
$\frac{3}{4}$–$1\frac{1}{4}$	Galvanized Wrought-Iron	835	598
2	Galvanized Steel	57,316	7,304
2	Galvanized Wrought-Iron	22,400	16,655

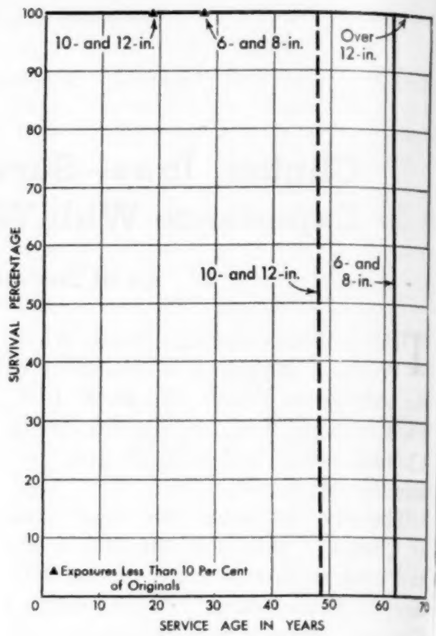


FIG. 2. Mortality Survival Curve—6–16-in. Cast-Iron Unlined Mains—Clinton, Iowa

BASE: Feet SURVIVAL: 1875–1940

SIZE *in.*	EXPOSURES *ft.*	RETIREMENTS *ft.*
6 and 8	66,411	12
10 and 12	4,828	276
Over 12	654	0

The town of Lyons, immediately north of Clinton on the Mississippi River, which was later incorporated in the city of Clinton, originally had its own supply furnished by the Lyons Water Works which was built in 1875. The source of supply was the Mississippi River and there was a steam pumping plant on the bank which pumped the water into an earth embankment reservoir from which it flowed by gravity into the distribution system. In 1891 the owners of the Clinton Water Works Company took over these works and operated them until about 1900 when the two systems were combined and supplied from the Clinton works.

For emergency service in case of insufficiency in well supply a filter system was installed in 1899 at the Clinton station to filter Mississippi River water. Its capacity was about 0.8 mgd. and consisted of low-service pumps for raising the water into a steel sedimentation tank from which treated

water flowed to the two gravity filters and thence to the clear well. There has been little occasion, however, to use these filters.

In 1926 the original pump station, which was a plain brick building, was replaced with a new building of more ornate appearance, largely because of local desire for a more pretentious building in the river front park.

The present water supply is obtained from six wells adjacent to the station which are drilled into rock to depths of from 1,135 to 2,100 ft. Water is pumped from these wells by air lift and flows through collecting pipes to a masonry suction well beneath the pump room floor. Adjacent to the pump station is a clear water reservoir originally constructed some time prior to 1900 and rebuilt and enlarged in that year to a capacity of 1.25 mil.gal.

The yield of the wells at the present time is about 6 mgd., varying in individual wells from 0.8 to 2.6 mgd. Air for pumping wells is furnished by two steam and one diesel engine-driven air compressors.

After chlorination the water is repumped to the distribution system which is in one service pressure without storage. The distributive pumping equipment is steam driven, with one 4-mgd. centrifugal pump driven by a gasoline engine for standby equipment. Standard station pressure is about 80 psi. which is raised when required for fire service to 110 psi.

Basis of Study

The data on pipe were compiled from a study made for the purpose of listing all pipe that had been retired over the life of the property. The study was made coincidentally with an inventory of existing mains. Company records of size, kind and date of installation were only fairly complete over the early life of the system. Only fully identified pipe were included in the study.

Mortality Survival Study

Mortality studies were made only of mains. Table 1 gives a summary of the pipe installed, identified, retired and the amount remaining in service, as well as the average ages, sizes and grouped mortality survival ratios. The major part of the pipe unidentified is still in service. Figures 1 and 2 show the mortality survival curves covering the record of the pipe grouped as shown. In explanation of the fact that several of the mortality survival ratios are shown as zero, it might be pointed out that this pertains when the entire amount of the oldest pipe formerly in service is retired in the last year of the record even though most of the pipe still is in service.

A brief summary of Class B facilities, exclusive of the original construction, is given below.

Causes of Retirement

There is no complete record from which could be determined the causes of retirement of mains in Clinton.

Acknowledgment

The collection and compilation of data pertaining to the Clinton Water Works Company were done by the personnel of the American Water Works & Electric Company, Inc.

Summary of Class B Facilities

Clinton, Iowa

Wells

No. 1—Drilled well, 5- and 8-in. diameter, 1,135 ft. deep, 250 ft. of 8-in. casing into shale, limestone and sandstone; pumped by air lift since 1917; capacity 350 gpm. Constructed in 1886 and still in service.

No. 2—Drilled well, similar to No. 1, 1,400 ft. deep, 250 ft. of 8-in. casing; pumped by air lift; capacity 500 gpm. Constructed in 1886 and still in service.

No. 3—Drilled well, similar to No. 1, 6- and 8-in. diameter, 1,685 ft. deep, 135 ft. of 8-in. casing; pumped by air lift since 1920. Constructed in 1890 and still in service.

No. 4—Drilled well, similar to No. 1, 5- and 8-in. diameter, 1,497 ft. deep, 200 ft. of 8-in. casing; artesian. Constructed in 1893 and retired in 1901 due to lowering of ground water.

No. 5—Drilled well, similar to No. 1, 8- and 12-in. diameter, 1,763 ft. deep, 850 ft. of 6-in. casing; pumped by air lift since 1922; casing replaced 1935. Constructed in 1902 and still in service.

No. 6—Drilled well, similar to No. 1, 10- and 12-in. diameter, 2,101 ft. deep, 10- and 12-in. casing; pumped by air lift since 1937. Constructed in 1910 and still in service.

No. 7—Drilled well, similar to No. 1, 12- 17- and 23-in. diameter, 926 ft. of 12- and 16-in. casing; pumped by air lift. Constructed in 1937 and still in service.

Purification Works

Sedimentation Tank—Open, riveted steel tank, 30-ft. diameter by 20 ft. high; capacity 100,000 gal. Erected in 1910 and still usable.

Filters—Two riveted steel, horizontal, gravity-type filters, 8-ft. diameter by 20 ft. long; capacity 0.4 mgd. each. Erected in 1900 and still usable.

Coagulating Tanks—Two open cypress tanks, 5-ft. diameter by 5 ft. high. Erected in 1910 and still usable.

Pumping Equipment

High-Service No. 1—Gordon Maxwell horizontal, direct-acting, compound, duplex, non-condensing steam pump; rated 2-mgd. capacity. Installed in 1888 and still in service.

High-Service No. 2—Worthington, direct-acting, duplex, triple expansion, condensing steam pump; rated 4.0-mgd. capacity; 174-ft. head. Installed in 1924 and still in service.

High-Service No. 3—Holly-Gaskill, horizontal, compound, crank and flywheel, condensing steam pump, rated 5-mgd. capacity; 231-ft. head. Installed in 1892 and still in service.

Low-Service No. 4—Worthington, direct-acting, compound, duplex, non-condensing, steam pump, rated 2-mgd. capacity. Installed in 1900 and still in service.

High- and Low-Service No. 5—Worthington, direct-acting, compound, duplex, non-condensing; rated 1.0-mgd. capacity. Installed in 1893 and still in service.

High-Service No. 6—American Well Works, two-stage, horizontal centrifugal pump; rated 4.0-mgd. capacity at 280-ft. head; directly connected to Buffalo 8-cylinder gasoline engine. Installed in 1937 and still in service.

Laidlaw-Dunn, direct-acting, compound, duplex, condensing steam pump; rated 3.0-mgd. capacity; 266-ft. head. Installed in 1896; retired for scrap in 1924.

Gordon-Maxwell, steam pump, specifications unknown. Installed in 1888; retired and sold to St. Joseph Water Co. in 1893.

Two Knowles, simple, single, double-acting, non-condensing steam pumps. Installed in 1876; retired in 1900.

Compressor No. 1—Sullivan horizontal, steam-driven compressor; 614 cfm. Installed in 1917 and still in service.

Compressor No. 2—Ingersoll-Rand, horizontal steam-driven compressor; 1,042 cfm. Installed in 1922 and still in service.

Compressor No. 3—Ingersoll-Rand, vertical compressor driven by De La Vergne, 3-cylinder diesel engine; 1,302 cfm. Installed in 1931 and still in service.

TABLE 1

Summary of Mains
Clinton, Iowa

Size, in.	Kind	Total Feet	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, yr.
$\frac{3}{4}$	Galvanized wrought-iron	237	237	0.1	0	0.0	237	0.1	1909	30.5
$1\frac{1}{4}$	Galvanized wrought-iron	598	598	0.3	598	2.4	0	0.0	1912	—
2	Galvanized wrought-iron	43,399	22,400	12.1	16,655	67.1	5,745	3.6	1890	25.8
2	Galvanized steel	57,316	57,316	31.0	7,304	29.4	50,012	31.3	1912	17.1
2	Cast-iron cement lined	5,411	5,411	2.9	0	0.0	5,411	3.4	1931	2.3
3	Cast-iron unlined	300	0	0.0	0	0.0	0	0.0	—	—
4	Cast-iron unlined	32,542	48	0.0	0	0.0	48	0.0	1930	9.5
6	Cast-iron unlined	143,527	54,549	29.6	12	0.0	54,537	34.1	1876	17.0
8	Cast-iron unlined	57,505	11,862	6.4	0	0.0	11,862	7.4	1910	19.3
10	Cast-iron unlined	24,436	562	0.3	276	1.1	286	0.2	1875	16.4
12	Cast-iron unlined	8,928	4,266	2.3	0	0.0	4,266	2.7	1922	15.7
16	Cast-iron unlined	654	0	0.0	0	0.0	0	0.0	—	—
6	Cast-iron cement lined	18,445	18,445	10.0	0	0.0	18,445	11.5	1929	7.1
8	Cast-iron cement lined	8,963	8,963	5.0	0	0.0	8,963	5.6	1930	5.1
Total		402,261	184,657	100.0	24,845	100.0	159,812	100.0		15.2
Percentage of Total			100.0		13.5		86.5			
Average Size, in.		4.9	4.5		2.1		4.9			

Mortality Survival Ratios

Size, in.	Kind	No. of Feet	Period Covered, yr.	Percentage
$\frac{3}{4}$–$1\frac{1}{4}$	Galvanized wrought-iron	835	31.5	28.383
2	Galvanized steel	22,400	27.5	0*
2	Galvanized wrought-iron	57,316	38.5	0*
4	Cast-iron unlined	48	9.5	100.000
6	Cast-iron unlined	54,549	62.5	0*
8	Cast-iron unlined	11,862	30.5	100.000
10–12	Cast-iron unlined	4,828	48.5	0*
Over 12	Cast-iron unlined	654	64.5	100.000
6–8	Cast-iron cement lined	27,408	10.5	100.000
Total		179,900		

* Due to fact that oldest pipe was retired in last year of record.

Summary of Installations and Retirements
Clinton, Iowa

MAINS

¾-in. Galvanized Wrought-Iron Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1909	237	237	0
1939	0	0	0
Total	237	237	0

1¼-in. Galvanized Wrought-Iron Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1912	598	0	598
1939	0	0	0
Total	598	0	598

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1912	200	1922	398	1939

2-in. Galvanized Wrought-Iron Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1890	534	0	534
1892	680	0	680
1895	1,200	0	1,200
1898	827	0	827
1899	159	0	159
1902	327	0	327
1903	1,095	0	1,095
1904	270	0	270
1906	968	0	968
1907	558	0	558
1908	1,844	0	1,844
1909	4,128	679	3,449
1910	3,460	1,258	2,202
1911	3,345	1,760	1,585
1912	1,411	796	615
1913	24	0	24
1916	450	450	0
1923	318	0	318
1924	68	68	0
1927	80	80	0
1928	135	135	0
1930	380	380	0
1934	91	91	0
1935	8	8	0
1937	40	40	0
1939	0	0	0
Subtotal	22,400	5,745	16,655
Unknown	20,999	18,387	2,612
Total	43,399	24,132	19,267

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1890	534	1928				
1892	400	1928	280	1929		
1895	1,200	1923				
1898	827	1926				
1899	117	1926	42	1929		
1902	285	1928	42	1929		
1903	395	1924	700	1928		
1904	270	1935				
1906	158	1922	377	1928	433	1939
1907	150	1927	84	1928	324	1929
1908	1,466	1923	68	1927	310	1929
1909	127	1922	382	1923	36	1924
	410	1925	695	1927		
1910	850	1926	593	1928	159	1932
	600	1939				
1911	373	1922	53	1924	278	1925
	554	1928	327	1939		
1912	48	1924	12	1926	377	1928
	48	1929	130	1936		
1913	24	1922				
1923	318	1939				

2-in. Galvanized Steel Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1912	216	0	216
1913	3,032	3,032	0
1914	2,338	2,189	149
1915	4,746	3,694	1,052
1916	2,840	1,776	1,064
1917	3,432	3,313	119
1918	217	0	217
1919	380	380	0
1920	1,805	1,572	233
1921	4,322	4,182	140
1922	3,006	2,781	225
1923	4,886	3,877	1,009
1924	3,084	2,885	199
1925	5,115	4,100	1,015
1926	3,328	2,913	415
1927	3,788	3,619	169
1928	4,124	3,177	947
1929	578	578	0
1930	3,194	3,108	86
1931	1,864	1,815	49
1932	185	185	0
1933	666	666	0
1935	58	58	0
1938	112	112	0
1939	0	0	0
Total	57,316	50,012	7,304

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1912	216	1939				
1914	54	1928	95	1937		
1915	504	1922	534	1926	14	1929
1916	138	1922	56	1923	136	1925
	82	1926	370	1928		
1917	61	1924	58	1939		
1918	180	1922	37	1936		
1920	127	1922	106	1926		
1921	50	1928	90	1937		
1922	120	1928	105	1939		
1923	320	1924	33	1928	108	1929
	548	1936				
1924	57	1925	142	1928		
1925	280	1927	511	1928	200	1929
	24	1930				
1926	415	1928				
1927	169	1928				
1928	141	1929	806	1932		
1930	40	1932	46	1939		
1931	49	1938				

3-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
Unknown	300	300	0
Total	300	300	0

4-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1930	48	48	0
1939	0	0	0
Subtotal	48	48	0
Unknown	32,494	31,604	890
Total	32,542	31,652	890

6-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1876	12	0	12
1901	436	436	0
1909	1,538	1,538	0
1910	2,257	2,257	0
1911	463	463	0
1912	536	536	0
1913	1,414	1,414	0
1914	52	52	0
1916	60	60	0
1917	2,184	2,184	0
1920	8,229	8,229	0
1921	1,623	1,623	0
1922	2,127	2,127	0
1923	2,187	2,187	0
1924	6,213	6,213	0
1925	4,902	4,902	0
1926	4,524	4,524	0
1927	3,895	3,895	0
1928	11,897	11,897	0
1939	0	0	0
Subtotal	54,549	54,537	12
Unknown	88,978	88,978	0
Total	143,527	143,515	12

Retirements by Years

Year Installed	Feet	Year
1876	12	1938

8-in. Cast-Iron Unlined Mains

Year Installed	*Feet Installed*	*In Service*	*Retired*
1910	366	366	0
1911	895	895	0
1913	1,296	1,296	0
1916	164	164	0
1917	1,992	1,992	0
1920	660	660	0
1921	840	840	0
1923	2,172	2,172	0
1925	1,199	1,199	0
1926	666	666	0
1927	808	808	0
1928	804	804	0
1939	0	0	0
Subtotal	11,862	11,862	0
Unknown	45,643	45,643	0
Total	57,505	57,505	0

10-in. Cast-Iron Unlined Mains

Year Installed	*Feet Installed*	*In Service*	*Retired*
1875	276	0	276
1923	276	276	0
1926	10	10	0
1939	0	0	0
Subtotal	562	286	276
Unknown	23,874	23,874	0
Total	24,436	24,160	276

Retirements by Years

Year Installed	*Feet*	*Year*
1875	276	1923

12-in. Cast-Iron Unlined Mains

Year Installed	*Feet Installed*	*In Service*	*Retired*
1922	2,316	2,316	0
1926	1,950	1,950	0
1939	0	0	0
Subtotal	4,266	4,266	0
Unknown	4,662	4,662	0
Total	8,928	8,928	0

16-in. Cast-Iron Unlined Mains

Year Installed	*Feet Installed*	*In Service*	*Retired*
Unknown	654	654	0
Total	654	654	0

2-in. Cast-Iron Cement-Lined Mains

Year Installed	*Feet Installed*	*In Service*	*Retired*
1931	79	79	0
1932	58	58	0
1933	54	54	0
1934	494	494	0
1935	111	111	0
1936	1,026	1,026	0
1937	790	790	0
1938	641	641	0
1939	2,158	2,158	0
Total	5,411	5,411	0

6-in. Cast-Iron Cement-Lined Mains

Year Installed	*Feet Installed*	*In Service*	*Retired*
1929	2,937	2,937	0
1930	6,893	6,893	0
1932	2,412	2,412	0
1934	1,065	1,065	0
1936	2,295	2,295	0
1937	676	676	0
1939	2,167	2,167	0
Total	18,445	18,445	0

8-in. Cast-Iron Cement-Lined Mains

Year Installed	*Feet Installed*	*In Service*	*Retired*
1930	3,960	3,960	0
1931	255	255	0
1934	688	688	0
1939	4,060	4,060	0
Total	8,963	8,963	0

Abstracts of Water Works Literature

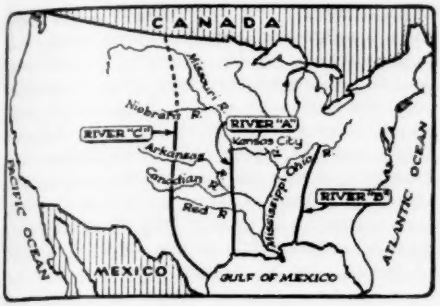
Key: In the reference to the publication in which the abstracted article appears, **34:** 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34:** 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British); I.M.—Institute of Metals (British).*

CONSERVATION, FLOOD CONTROL AND IRRIGATION

Rates of Sediment Production in Southwestern United States. CARL B. BROWN. U.S. Soil Conservation Service Bul. Sediment one of major problems in utilization of water resources of southwestern states. Examples: 5,000,000 acre-ft. reserved behind Boulder Dam for silt storage. Elaborate desilting works at diversion of new All American Canal. Accurate records of silt load meager and widely scattered. This publication attempts to compile, evaluate and translate into comparable units all known data on streams in Great Basin, Colorado and Gila R. watersheds, Rio Grande and Pecos R. watersheds above junction. Long-term avg. annual sediment production evaluated. Records often poor because recognition of importance about 50 yr. behind times. *Accuracy of Suspended Load Data:* Many records based on suspended load sampling computed in manner giving systematic underest. Others give arithmetical avg. of several samples without weighting discharge. Different types of samplers for suspended load give different results up to 46%. Reported long-term total suspended sediment load less than total sediment load because (a) method of sampling, (b) infrequency of sampling and method of computation, (c) unmeasured bed load and, (d) subnormal runoff in sampling period (in many records). *Accuracy of Reservoir Sedimentation Data:* Soil Conservation Service tested in 10 detailed reservoir surveys for limits of error in capac. and sediment vol. detn. Max. difference 4%− and avg. 1%−. Accuracy of many varieties of reconnaissance surveys of sediment tested by comparison with detailed surveys. Regardless of method 80% of reconnaissance surveys give annual sediment accumulation within 30%± while 20% give errors of 30–75%. Errors equally distributed between plus and minus. Instructions prepd. by Soil Conservation Service. Specialist in such reconnaissance surveys should be able to measure sediment within 10% error in 80% of reservoirs and maximum should not exceed 30%. Reconnaissance surveys made in from ½ day for ponds to 3 days of several hundred thousand acre-ft. Errors result in converting measured vols. of sediment to tonnage. *Long-Term Rates of Sediment Production:* Vegetation cover sparse over most of southwest and erosion rates therefore high. Sediment production largely function of pptn. Arroyo development has been large since introduction of stock raising about 60 yr. ago. Area feeding sediment into main stream channels has enormously expanded and arroyos themselves have been large source. No quant. proof exists that sediment loads larger or rate increasing but all records obtained since overgrazing and deforestation occurred. Ests. of long-time stream flow on Rio Grande, Colorado and Truckee rivers show that since '17 to '25 discharge very deficient. More reliable suspended load records of sediment obtained in this deficient period. Annual suspended load at various stations on Colorado R. and tributaries when platted on log-log paper gives curves defined by Eq. $S = cR^x$, where S = annual suspended load, R = annual runoff and c = coef. For recorded data from Grand Canyon Station on Colorado R. equation contains values $S = 0.00295\ R^{1.52}$. Other stations have different values for c and x but in all exponent greater than unity showing that greatest sediment concn. in years of

greatest runoff. Curves used to est. long-time sediment concn. from short records but on Rio Grande at San Marcial, which has fairly accurate record of suspended load since 1897, 15% added to take care of bed load. At San Marcial, due to unique characteristics of watershed annual points of sediment load scatter widely when platted but show same general characteristics. REGIONAL CHARACTERISTICS. *Great Basin:* On higher parts of mountain ranges bordering and with pptn. above 25″ with substantial part as snow, sediment production low: 100–800 tons/sq. mi. *Southern California Coastal Ranges:* Slopes very steep, inherently unstable thin soil mantle, vegetal cover not very good, occasional high intensity storms: long-term sediment production 1000–1500 tons/sq.mi. Intense storms 10 times that. *Base of Mountain Ranges Bordering Great Basin:* Subject to summer cloudbursts. Vegetation cover extremely variable and sediment related to watershed cover deterioration. In lower parts of canyons 1500–3000 tons/sq.mi. for long-time avg. and 5000–10,000 tons for individual storms. Away from eastern and western margins of Great Basin: long-time mean 100–300 tons/sq.mi. COLORADO RIVER. Desilting of river due to Lake Mead makes all measurements below prior to '35 inapplicable. Records now being obtained on Colorado and major tributaries by U.S.G.S. form best long-time record of suspended load in U.S. Suspended load estd. at 95% of total load. Williams R. has avg. silt yield of 629 tons/sq. mi. by one est. and 1157 tons/sq.mi. by reconnaissance sedimentation survey of Lake Havasu. In Utah portion of Green R. rates in order of 1500–3500 tons/sq.mi. In mountainous Upper Colorado, 100 tons/sq.mi.; middle section, 500 tons/sq.mi.; above junction with Green R., 1300 tons/sq.mi. Colorado plateaus give greatest sediment loads. San Juan from east and streams from northwest entering Colorado below junction with Green give long-term rates of 3000–4000 tons/sq.mi. but may be 6000–8000 tons/sq.mi. for smaller areas. Sediment concn. in runoff astonishingly high—8.52 and 7.55%. In Virgin R., 1.73%; Little Colorado, 7.55%. Zuni watershed has higher sediment production but lower concn. Gila R. gave annual silt production estd. at 518 tons/sq.mi. for head waters and up to 2732 tons/sq.mi. in Duncan subdivision. Silting of San Carlos Res. estd. at 7586–8492 acre-ft. per sq.mi., variation being due to difference in ests. of runoff. Load in Lower Gila variously estd. at 487–566 tons/sq.mi. For 57,000 sq.mi. this equals 15,000–16,000 acre-ft. total. RIO GRANDE. Much work done on Rio Grande and tributaries above Elephant Butte Res. Max. content, weight of dry sediment to weight of sediment and water mixture, has been observed as follows: San Acona 17.27%, Rio Puerco 52%, Jemez R. south of Pueblo Zia 59%. In 5 yr. of '36–'41 over 12,000 acre-ft. per yr. accumulated in Middle Rio Grande Valley distributed as follows: 25% in 133-mi. long floodway of Middle Rio Grande Conservancy Dist., 20% in areas flooded by levee breaks, 55% in 14 mi. just above Elephant Butte Res. Avg. long-time annual sediment mean passing San Marcial = 26,000,000 tons. PECOS RIVER. Sediment records far from satisfactory but believed that sediment production per avg. yr. about as follows: Above Las Vegas and western rim of higher mountains (pptn. 18″+), 100–300 tons/sq.mi.; where pptn. is 14–18″, 300–2000 tons/sq.mi.; in central and southern portion of watershed 200–600 tons/sq.mi. Some avg. recorded annual suspended sediment loads are: Green R. at Green River, Utah, 24,000,000 tons; San Juan R. at Bluff, Utah, 44,000,000 tons; Colorado R. at Grand Canyon, 200,000,000 tons. Long-time avgs. would be higher.—*Harold Conkling.*

A Solution to the Mississippi River Problem. J. KENNARD THOMSON. (*Abstracted from address to The Broadway Assn.*) Eng. Jour. **26**: 468 (Aug. '43). Mississippi R. flood of '27 worst since 1844. Estd. flow 3½ million cfs. while that of Niagara R. avgs. only 220,000 cfs. More than million citizens suffered direct loss and millions of cultivated acres flooded. More than billion dollars, 200 lives lost. 700,000 people lost homes. Mississippi R. drainage area 1,240,000 sq.mi. or 41% of U.S. *One river can never be made safe* to drain that area. Levees near New Orleans try to hold water 50′ above surrounding country. Break floods country 250 mi. into Texas while repair expenses enormous. Safe and profitable job can be done by constructing 3 new rivers A, B and C (see map), then reconstruct present Miss. and connect these by Arkansas, Canadian and Red rivers to regulate flow when one dry and others in flood. Work on A, B and C should start at Gulf of Mexico. As each 50 mi. completed, use for navigation, etc. A would extend 700 mi. to Kansas City; B,



700 mi. to Ohio R.; and C, 1000 mi. to Niobrara R., later to Canadian border. These 4 rivers should have non-corrodible lining for sides and bottom, be 25–40′ deep and sufficiently wide for safety. Would be 500–3000′ drop from northern end to Gulf, representing enormous potential water power. Should provide storage basins to save present annual billion cu.yd. top soil now washing into Gulf. Water power development, irrigation, reclamation, reforestation, etc., would add greatly to project value. Instead of huge annual loss from floods and droughts, cost returned in profits many times and entire continent greatly benefited.—*Ralph E. Noble.*

Extremes of Rainfall. C. E. P. Brooks. Wtr. & Wtr. Eng. (Br.) **47**: 546 (Dec. '44). Heavy rainfall requires air contg. large amt. of water vapor and some means of cooling this air by raising it rapidly to high level. Hence places with heaviest annual rainfalls are where mountain range fronts moist unstable wind. Classical example is Cherrapunji on Khasi Hills in Assam. Avg. for present official station (Cherrapunji) is 424.1″ per yr. Nearer center of plateau fall is up to at least 450″ per yr. 5-yr. avg. at Manoyuram gave 498.7″. Monthly avg. at official station in in. are: Jan. 0.5, Feb. 2.7, Mar. 9.4, Apr. 28.2, May 46.3, June 95.9, July 98.5, Aug. 79.8, Sept. 38.0, Oct. 21.3, Nov. 3.2, Dec. 0.3. Somewhat similar conditions exist where southwest monsoon from Arabian Sea strikes Western Ghats. At one place 440″ fell on 31 consecutive days. Similar part played by Cameroon Mts. in relation to southwest monsoon of Africa. At Debundscha annual avg. was 378.6″ of which over 70% fell from June to Oct. Northeastern slopes of mountainous Hawaiian Id. are exposed to Pacific trade winds. On Mt. Waialeale 13 yr. of record gave avg. of 442.4″. Rainfall fairly evenly distributed throughout year. In temperate regions greater wind strength does not compensate for smaller vapor content of air. Examples are: Glaslyn, Snowdonia 198″ in.; Norway 124″; Alaska 177″; New Zealand 198″. By contrast areas to leeward of mountain ranges have small rainfall but driest weather occurs where conditions are persistently anticyclonic and prevailing winds blow from colder regions. In Sahara years have been known to pass without rain. Similarly southwest Africa, western Australia and northern Chile have little rainfall. Northern Chile probably includes driest parts of earth's surface. At Puerto de Arica there was only one fall of 0.4″ in 20 yr. Conditions in Atacama desert suggest that no appreciable rain has fallen for centuries. In shorter periods 3 main types of intense rains: orographic rain, which may give 30″ or more a day for several successive days; typhoons, which give largest 24-hr. totals; and violent instability storms, generally thundery, which give rains of greatest intensity but of relatively short duration. One of heaviest known falls in 24 hr., 46.0″, at Baguio, Philippines, part of 81.4″ in 3 days. Heaviest known rainfall in a day in England 9.56″ at Bruton. Heaviest known fall in 1 wk., 20.57″ at Ben Nevis. Records of heavy rains in short periods innumerable. Large collection of records published by J. R. Theaman in "Heavy Rainfall Records." When log of "normal maxim" plotted against log of time in which they fell, points fell on straight line which represents relation: $R = 0.4\ t^{0.6}$, where R is rainfall in in. and t time in min. For "freak" falls, $R = t^{0.54}$. Largest hailstones measured had diams. exceeding 5″. Four rainfall records stand well above broken line in Fig.: 8″ in 15 min. at Jamaica; 8.07″ in 20 min. in Rumania; 9.25″ in 30 min. in Virginia; and 23″ in 4 hr. on St. Kitt's. Two equations may be of interest as giving for any of rainier parts of world: (1) limiting intensity of rainfall which need be considered for practical purposes; and (2) limiting rainfall, odds against occurrence of which at any one place in any 1 yr. are of order of million to one.—*H. E. Babbitt.*

The Measurement of Rainfall on Windy Slopes. J. Glasspoole. Wtr. & Wtr. Eng. (Br.) **47**: 550 (Dec. '44). Methods adopted by G. L. Hayes in Northern Rocky Mt. Forest quite different from that adopted in

England. Exposure of rain gage can be considered to be sufficiently near normal if wind at level of rim of gage does not exceed 10 to 15 mph. Expts. showed that catch of gage exposed to strong winds could be improved by setting up turf wall around gage. In expts. in U.S. gages fitted with funnels constructed so that rim has same slope as ground on which gage being erected. Gage set in pit with splash mat. Although design is said to stop rain splash, ineffective for large hail. Conclusion reached that high deg. of accuracy can be obtained in windy slopes by use of these sloped orifice gages in pit exposures.—*H. E. Babbitt.*

Notes on Annual Rainfall With Special Reference to the Recurrence of Alternate Wet and Dry Groups of Years. J. W. MADLEY. Wtr. & Wtr. Eng. (Br.) **47**: 538 (Dec. '44). "Wet years" those with rainfall greater than avg.; "dry years" those less than avg. Study of rainfalls at Burnham and Oxford leads to conclusions regarding annual rainfalls at these stations: (a) Continuous succession of groups in which group yearly avg. alternately above and below general yearly avg. of station. (b) Number of years in each group varies considerably. (c) Within groups there are sub-groups with rising or falling steps not sufficiently large to cross general avg. at station. (d) Avg. annual rainfall at these stations changes by definite steps about every 6 yr. (e) Ratio of highest to lowest annual rainfall may be taken as practically same for both stations. (f) Distr. of rainfall throughout a year, or throughout group of consecutive years, sometimes of greater importance than total rainfall for particular year in detg. quant. of water available during drought years. Results of further investigations of Chilgrove and Spalding rainfalls confirm conclusions already noted with respect to Burnham and Oxford rainfalls. In addn.: (a) They show that conclusions arrived at for Burnham and Oxford apply to areas outside Thames Valley. (b) Indicate points of value to water engrs., especially in detg. provision to be made to insure adequate water supply during periods of drought. (c) They show that avg. figures for England cannot be applied to particular localities, because drought years do not synchronize all over country, and so severity of droughts ironed out in avgs. of number of stations. (d) Consequently, every water authority would be well advised to keep records for its own catchment area, including rainfall, yield and underground water levels. (e) No definite regular cycles of annual rainfall appear to be indicated by tables and diagrams. (f) Compared with station long-period avg. annual rainfall, max. rainfall in 1 yr. is about 150% and min. about 55% of its value. (g) Duration of wet and dry groups varies considerably. Avg. is about $5\frac{1}{2}$ yr., and difference between avg. annual rainfalls of adjacent groups is about 20% of avg. annual rainfall of station.—*H. E. Babbitt.*

Rôle of the Land During Flood Periods. W. W. HORNER. Proc. A.S.C.E. **69:** 665 (May '43). Rôle of land is that which dets., from any specific pptn. period, stream-channel inflow which will result directly therefrom and which will occur during or immediately following that period. This rôle not peculiarly related to "flood" periods, but land effect during flood periods merely special case of effect during any period of pptn. Principal controls of land are surface retention, infiltration capac., surface detention, subsurface detention, subsurface storage and facility for quick subsurface return outflow to stream. Principal controls which land exerts along paths which pptn. at soil surface may take in direction of contributing to stream-channel inflow are: interception, separation at soil surface, storage, detention and runoff. Interception by vegetal cover may be negligible with respect to major floods, but may affect magnitude of minor floods appreciably. Depression storage represents water trapped on surface in depressions. Evapn. during storm period, in general, materially less than 0.01" per hr. and of little importance even with respect to minor floods. Infiltration capac. is:

$$f = \frac{P - Q - s}{\Delta t}$$

in which Δt = mean time of infiltration opportunity; P = pptn.; Q = surface runoff; and s = surface storage or retention. In Class 1, infiltration capac. small to moderate and stream-channel inflow occurs predominately as surface runoff. In Class 2, infiltration capac. generally large and stream-channel inflow as surface runoff small part of whole. In studying rôle of land in detg. stream-channel inflow within east fork of Trinity River drainage basin in Texas, methodology employed involved: (1) collection and correlation of all available pptn. data for each of 35 storms; (2) prepn. of most probable pptn. intensity patterns; (3) derivation of infiltra-

tion capac. curves for Blackland soil and various classes of vegetal cover; (4) correlation of infiltration capac. with antecedent conditions; (5) application of derived data to evaln. of surface runoff; (6) computation of excess rainfall, hr. by hr., throughout storm; (7) transformation of pptn. excess into mean values on each of 10 subareas; (8) comparison of mean computed surface runoff with actual surface runoff; (9) detn. of excess rainfall for "after" conditions; (10) computation of flood-flow reduction resulting from effective adoption of program; and (11) detn. of flood-stage reduction, and reduction in area inundated. In studies of rôle of land during flood periods, system of bookkeeping needed that will reveal values of infiltration capac. and of utilizable soil storage capac. in their occurrence pattern over considerable period of years. Although flood flow cannot be unscrambled from large basins, engr. can reverse process and use measured flood flow as check on synthetic computations. *Discussion. Ibid.* **69:** 911 (June '43). L. K. SHERMAN: Rainfalls on same basin or plot occurring in same month or season generally in such agreement that they will furnish composite curve of infiltration capac., sometimes called *f*-curve. Procedure for deriving curves of infiltration capac. from natural rainfall include: (1) *Horner method:* Requires hydrographs of runoff closely synchronized with rain sequences or pattern. Method applies to plots and small basins. (2) *Sharp and Holtan method:* Requires hydrographs of runoff. Applies to small plots and large basins. First, mass curve of infiltration derived, and, from this, *f*-curve found. (3) *Sherman and Mayer method:* Requires derivation of avg. filtration capac. for storm, f_a, and min. infiltration capacity f_c. Requires only total vol. of surface runoff. *f*-curve found first, mass curve of infiltration derived from it. Applies to small plots and large basins. *Discussion. Ibid.* **69**: 1138 (Sept. '43). RAPHAEL G. KAZMANN: Throughout paper misleading use of word "porosity." Ability of material to function as "conduit" for transmission of water generally known as material's permeability. Porosities of water-bearing materials bear little relationship to their permeabilities. W. G. HOYT & W. B. LANGBEIN: Evaluation of hydraulics of land use during flood periods accomplished by complex and speculative technics. True because: (1) lack of basic knowledge concerning land phase of runoff; (2) wide variations in infiltration capac. and other hydrologic conditions within drainage basin; and (3) lack of demonstrated beneficial change in flood-runoff regime of any large stream because of change in land use. Expanded title of author's paper might well read "Rôle of Land During Flood Periods in Those Areas Where Infiltration Capacity Is Low to Moderate, Where Infiltrated Water Does Not Appear in Stream as 'Quick-Subsurface Return Flow,' and Only During Periods of No Snow, Ice or Frost." Author suggests that ratio between observed surface runoff and computed rainfall excess test of validity of his procedure. Examn. of author's unpublished reports indicates that computation of rainfall excess influenced to considerable extent by knowledge of actual volume of runoff. Obvious that wide departures from observed runoff have been adjusted to arrive at result more closely in conformance with observed runoff. Test not same as would be met by forecaster with no knowledge of runoff to be produced by storm other than that provided by his working formulas. Query raised as to use of term "regression curves." Lines or curves of "regression" statistical terms devised by Galton to describe lines or curves of best fit between single independent variable and one or more dependent variables. More descriptive term should be devised.—*H. E. Babbitt.*

Flood Control at Franklin Falls. J. H. CORNELL. The duPont Mag. **36:** 6–7: 13 (June-July '42). Congress passed Flood Control Act, '36, authorizing U.S. Engrs. to tame Merrimack R. for safety of 810,000 pop. in 5015-sq.mi. watershed. Dams projected: Pemigewasset, 2; Contoocook, 2; Suncook, 1; and Blackwater, 1. Pemigewasset R. and Winnepesauke R. meet to form Merrimack R. Franklin Falls Dam under constr. 2½ mi. north in bed of Pemigewasset R. Broad-based river barrier consists of rock, gravel, earth and sand forming body of structure; approach channel, concrete-lined, leading to 2 twin horseshoe-shaped concrete-lined conduits under operating house; dischg. channel emptying into stilling basin, and, on west side, spillway section as long as Wash. monument is high. Control gates in 27′ twin conduits now in place. Other essential points: Drainage area, 1000 sq.mi.; reservoir capac., 56 billion gal.; dam width at base, 1380′ overall, at top, 35′; height, 131′; total excavation at site, 3,260,000, fill in dam, 3,500,000, and concrete, 76,000 cu.yd.; total cost, $4,350,000; completion in fall of '42.—*Ralph E. Noble.*

Boise River Overflows Banks: Damages Bridges, Roads and Weirs. ANON. Western Constr. News **18:** 220 (May '43). In history of Boise R., heaviest flood, Apr. 17 to 26, damaged roads, bridges and inundated 40 sq.mi. of rich farm land, much seeded. With normal flow of 9000 cfs., seldom exceeding 13,000 cfs., river rose to peak of 23,000 cfs. Aside from heavy crop and livestock loss, principal damage to irrigation headgates, weirs and dikes. Mid-Dec. warning resulted in widening and dredging channel, straightening dangerous meanders, raising dikes and effecting other protective measures. Arrowrock Reservoir had been kept at low level to cushion crest from upper Boise. Reservoir capac. rated at 282,000 acre-ft., less some reduction due to accumulated silt in 30 yr. [Silt accumulation preventable or reducible to min., thus greatly increasing life of reservoir, according to principles outlined in "Stratified Flow in Reservoirs and Its Use in Prevention of Silting." U.S. Dept. Agric. Misc. Bul. 491 (Sept. '42)]. In 5 days, Apr. 17, water went over spillway. Bridge and highway damage detailed.—*Ralph E. Noble.*

High-Intensity Rainfall at Larchmont. ARTHUR RICHARDS. Eng. News-Rec. **129:** 439 (Sept. 24, '42). Rainfall of unusual intensity occurred at Larchmont, N.Y., on July 27, '42, max. intensity in in. per hr. for 5, 10 and 60 min. being 6.00, 5.28 and 3.59, resp. Latter figure greater than those in Merriman's tables for highest rainfall recorded in U.S. Area of storm about 200 sq.mi., with Larchmont watershed about center of most intense pptn. During 2-hr. period, about 268 mil.gal. fell on 2.74-sq.mi. watershed. Considerable damage done. *Discussion. Ibid.* **129:** 695 (Nov. 19, '42). G. G. COMMONS, QUINTON B. GRAVES & R. S. GOODRIDGE: Data presented on greater rainfall intensities than at Larchmont.—*R. E. Thompson.*

Steel and Water. G. R. REISS. Am. City **58:** 11: 38 (Nov. '43). In eastern Ohio, Mahoning R. Valley, center of large steel industry periodically faced with droughts and floods. Youngstown and Niles built 2 dams for water supply, but other communities and many steel plants continued drawing from pold. Mahoning R. In '41 these dams insufficient during drought. U.S. engrs. quickly built 27-bil.gal. Berlin Dam on Mahoning R. Proved to be insufficient both for flood protection and water supply. In near future a new reservoir on Mosquito Creek, designed for 3 mo. completion with storage capac. of 38 bil.gal. at estd. constr. cost of $5,500,000, will be built. No spillway in dam, but excessive flows will pass through natural depression in reservoir into adjoining Lake Erie watershed. Believed to be only stream with 100% flood control.—*F. J. Maier.*

Yearbook of the Hydrology of Germany. 1938. Gas-u. Wasser (Ger.) **86**: 249 ('43). Contains hydrol. information on drainage areas of all rivers of Germany. Includes list of all water gages installed and gives statistical data obtained from them. Survey of hydrol. conditions in '38, list of tech. terms relating to surface water, and information on temps. of waters, on ground water levels and on yields of springs also included. List of tech. terms relating to ground water in course of prepn.—*W.P.R.*

Stream-Gaging Procedure. D. M. CORBETT *et al.* Water Supply Paper 888. U.S. Dept. of Interior, Geol. Survey ('43). Importance of stream-flow records in connection with many war activities emphasizes need for certain standardizations in order that work may be conducted efficiently and economically. This manual embodies results of work of hundreds of U.S.G.S. engrs. active in all sections of the country over period of many years. Information given relates to both science of flow of water in open channels and to art of measuring and recording river discharge. Because technic followed perhaps as important as instruments and equip. utilized, much attention given to details of field procedures found to yield best records of river flow. Manual will be useful in connection with training of eng. students and will also serve as aid to practicing engrs. who may be called upon to measure and record flow of streams, as it contains much new and valuable information not to be found elsewhere in eng. lit.—*Ed.*

Third Biennial Report of the Tri-State Waters Commission. ROBERT L. BARD. (Dec. 15, '42). Tri-State Waters Com. created by compact between N.D., S.D. and Minn. June 23, '37, consented to by Act of Congress, approved Apr. 2, '38. Com. composed of 3 members from each state. Urgent water need of Red R. of North Drainage Basin is control of floods from spring runoff and conservation of available water supply for

domestic use and for diln. of urban and indus. wastes. Com. rôle advisory only. Attempts to correlate plans and prevent unnecessary duplication of effort. Lake Traverse Bois de Sioux project completed. Consists of White Rock dam, Reservation Highway dam, Bois de Sioux Channel improvement and Browns Valley dike. These described. '42 excessive spring rains demonstrated advantage of planned flood control and water conservation. Estd. 42,000 acres saved at critical time of country's need for its cultivation; crop savings approx. $502,400. Addnl. projects in progress: Park R., Forest R., Goose R., Cheyenne R.-Baldhill Dam, Roseau R., Red Lake R. and tributaries, and Missouri R. diversion.—*Ralph E. Noble.*

The Rainfall of 1943. J. GLASSPOOLE. Wtr. & Wtr. Eng. (Br.) **47**: 157 (Apr. '44). Rainfall of '43 over England and Wales less than avg., while over Scotland and northern Ireland there was substantial excess. Deficiency in England and Wales always more serious than in Scotland or Ireland.

	Avg. Rainfall, *in.* 1881–1915	1943	Difference From Avg. *in.*	Avg. %
England and Wales	35.2	33.3	− 1.9	94
Scotland	50.3	54.1	+ 3.8	108
Northern Ireland	39.7	41.8	+ 2.1	105

While rainfall of '43 gave less than avg. in many parts of country, deficiency nowhere unprecedented.—*H. E. Babbitt.*

Flood Control. G. H. OCKENDEN. Surveyor (Br.) **104**: 177 (Mar. 30, '45). "Flood control" term covering vast field from improvement of rivers draining hundreds of square miles to small roadside ditch. Flood control not necessarily flood prevention. Many factors enter into max. runoff, such as, size and shape of area drained, type of soil, cultivation, slopes and levels, and hydr. conditions of tributaries and channel itself. It would be desirable if all river improvement schemes could commence at mouth and gradually work to upper reaches. Suggested that we now suffer from more severe floods than in distant past but no evidence that we get greater rainfall. Study of Ordnance Survey Report on "Subsidence of London" shows possibility of land in Essex and Kent having sunk some 18" to 24" in course of 60 yr. Solution may not be mere raising of flood embankments to cope with amt. of subsidence but installation and running of pumping plant may become necessary. In natural state rivers comprise river proper and flood plain. Latter may be narrow or miles wide. Hydr. conditions of channel can usually be improved, resulting in increase in capac., but in case of rivers running through agric. land, seldom economical to enlarge and deepen channel to take all flood water. Method generally adopted in country areas is to erect levees. When enlarging and improving gradient on natural channel, care must be exercised, for if channel is widened too much it will not be many years before river makes up for itself new bed within improvement, piles up new banks, etc. Small rivers through urban areas usually constructed to take whole of normal flood water because of expensive property abutting. In Birmingham problem has been to increase storm capac. of rivers and brooks mainly passing through densely built-up areas. Problem not only prevention of flooding but also to lower flood level in order that storm water culverts and overflows may operate without back-pounding (sic). Effect of land drainage on flood flows is, in general, time lag. Up to satn. point of ground, flow will be less, but when satn. point reached greater runoff may be expected. Found by observation and records that curve can be drawn giving fair relation between intensity and duration of rainfall that can generally be expected for normal storms. Catastrophic rainfall curves have also been produced for use when designing reservoir spillways.—*H. E. Babbitt.*

The Influence of a Changing Impermeability Factor on Surface Water Runoff. W. H. ELGAR. Surveyor (Br.) **103**: 543 (Nov. 10, '44). Heavy rainfalls, particularly those of short duration, occur generally when catchment area is dry, with consequence that impermeability factor commences at zero and increases to some max. value reached either at or before termination of rainfall. Max. rate of rainfall dependent on ratio of time of concn. of area to time occupied in reaching max. impermeability. In case of catchment area of stream max. impermeability generally reached only after considerable time, and 100% impermeability seldom reached. Quant. of rainfall required to produce max. impermeability variable in same catchment area.

Greater quant. required to produce satn. if intensity of rainfall low. Period of rainfall to produce max. impermeability is function of time of duration of storm. Short intense rainfalls do not produce max. rate of runoff from small area which would be expected by normal methods of calcn. "Entrance allowance" has been abused at times to cover this discrepancy. It is time of flow of rainfall outside of sewer. If catchment area initially dry, entrance allowance not quite const. but becomes shorter as rainfall proceeds until it eventually becomes const. Exceedingly important that max. impermeability and its rate of change should be accurately detd. as they have marked effect on max. rate of flow from area when subjected to storms of longer duration and higher intensity than that of time of concn. Conclusions: In case of areas with longer times of concn. error arising through disregarding possible change of impermeability is small and error arising through disregard or inaccurate use of entrance allowance is small. In case of areas with shorter times of concn. neglect of possible change of impermeability and inaccurate entrance allowance may lead to considerable errors in estg. max. rate of flow. Max. rate of flow occurs at end of period of rainfall irrespective of whether impermeability factor const. or increasing. If impermeability of area increases during rainfall then max. rate of runoff less than that caused by area whose impermeability remains const. at max. value unless duration of storm exceeds time of concn. If impermeability of area increases during rainfall, max. rate of rainfall caused by some storm of longer duration and lesser intensity than that corresponding to time of concn. Total amt. of rainfall required to bring catchment area to max. state of impermeability increases as intensity decreases, and is dependent in some deg. on climatic condition at time.—*H. E. Babbitt.*

Surface Water Runoff From Small Areas. L. B. Escritt. Surveyor (Br.) **103**: 583 (Dec. 1, '44). Common knowledge that drains from large bldgs. having very short times of concn. may be designed to rates of rainfall far lower than required by Ministry of Health std. curve without inadequacy becoming apparent. Comparatively short drains will pass considerably more than rated values as result of moderate surcharge without flooding occuring. Ministry of Health std. curve applied in conjunction with Lloyd-Davies method has become recognized as basis of sewer design in Great Britain which has times of concn. between 5 and 100 min. Soakaways have been largely used for absorbing runoff from roofs and paved areas. Common practice for builders to arrange for surface water drains to discharge to holes dug in ground and filled with rubble, proportions of which are detd. by guess work. When new soakaways tested, found that rate of soakage varied directly as head of water above bottom of chamber. Upon above basis, capac. of soakaway can be expressed as: $c = A^{1.4} \div 2085s^{0.5}$ in which c is capacity of soakaway in cu.ft.; s is rate of soakage when chamber is full, in cu.ft./min.; and A is impervious area drained, in sq.ft.—*H. E. Babbitt.*

Rapid Calculation of Runoff. L. B. Escritt. Surveyor (Br.) **104**: 170 (Mar. 23, '45). Formula $R = \frac{7}{t^{\frac{1}{2}}}$ devised because simplicity and form make it easy to use for prepn. of graphs. If value $\frac{7}{t^{\frac{1}{2}}}$ substituted for R in Lloyd-Davies formula, latter becomes $Q = \frac{423.5Ap}{t^{\frac{1}{2}}}$ where Q is runoff in cfm.; Ap is impermeable area in acres; and t is time of concn. in min.—*H. E. Babbitt.*

The Assessment of Percolation. David Lloyd. Wtr. & Wtr. Eng. (Br.) **47**: 308 (July '44). Assessment here discussed is avg. annual increment to ground water. Stated simply: rain falls on top soil and, when soil moisture reaches field capac., surface runoff occurs and some water seeps to zone of satn. Evapn. depletes amt. of soil water (Es). After interval outflow from underground reservoir effects return to avg. state of equilibrium and decrement disposed of by evapn. (Eg) and ground water effluent. On avg. decrement equals increment. Rainfall = total runoff + total evapn. loss. Rainfall − Es = surface runoff + net intake. It would appear most unreasonable to take avg. annual increment to ground water, or net intake, to be approx. ground water evapn. loss + 4 times dry-weather flow. To make any of these calcns. accurate values of avg. rainfall, mean temp., mean amt. of sunshine experienced over drainage basin and dry-weather flow must be known so that correct interpolation in graphs produced in "Evaporation Loss From Land Areas" can be made.—*H. E. Babbitt.*

American Water Works Association

Tentative

STANDARD SPECIFICATIONS

for

DEEP WELLS

These "Tentative Standard Specifications for Deep Wells" are based upon the best known experience and are intended for use under normal conditions. They are not designed for unqualified use under all conditions and the advisability of use of the material herein specified for any installation must be subjected to review by the engineer responsible for the construction in the particular locality concerned.

Approved as Tentative by the Board of Directors of the A.W.W.A. on April 30, 1945

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Tentative

Standard Specifications for Deep Wells

Introduction

Scope

These tentative specifications and accompanying appendix are intended as a guide in the preparation of contract documents governing well construction.

Because of the broadness of the well drilling field and the fact that these specifications cover construction, rather than material or equipment alone, they cannot be used verbatim, but must be supplemented and modified by the user to fit the particular needs and conditions of his own case. Although these specifications should be of considerable help in the preparation of contract documents, their use will not obviate the necessity of careful study of each individual problem nor lessen the desirability of obtaining competent technical advice for the larger or more unusual installations.

Appendix

An appendix is provided with these specifications to assist the user in filling in the blanks left herein and in making modifications, additions or changes. The appendix is necessary because the specifications must cover such a variety of types of wells, including those in consolidated formations (rock wells), those in unconsolidated formations (sand or gravel wells) and wells of varying size and depth and method and type of construction. In making use of the standard specifications, the appendix should be consulted freely. The appendix covers:

Section

A1-1—Forms of Proposal
A1-2—Form of Measurement and Compensation Clauses
A1-3—Information Relative to Local Conditions
A1-4—Description of Work
A1-5—Well Casings
A1-6—Well Screens
A1-7—Testing for Yield and Drawdown
A1-8—Grouting and Sealing
A1-9—Plumbness and Alignment
A1-10—Disinfection
A1-11—Protection of Quality of Water
A1-12—Shooting or Blasting

Other Contract Documents

Strictly speaking, the specifications are that part of the contract documents relating to the materials and equipment to be used, the method of performing the work and a description of the job as completed. In general practice, however, the term "specifications" is used loosely to cover the notice to bidders, form of proposal and form of con-

tract, as well as the specifications. No form of proposal is included herein but alternate forms are set forth in Sec. A1–1 in the Appendix. Similarly, no form of contract is included but various methods of payment, sometimes specified in the contract, are discussed in Sec. A1–2 in the Appendix.

The contract or the general specifications should cover the following items, among others:

1. Enumeration of contract documents
2. Brief description of work
3. Definitions of "owner," "contractor," "engineer," "notice," and terms such as "directed," "acceptable," etc.
4. Time of initiation and of completion of work
5. Liquidated damages for delay
6. Extra work
7. Contractor's insurance
8. Maintenance
9. Time and method of payment
10. Owner's right to make changes

Section 1-1—General

Sec. 1–1.1—Scope of Work

The work to be done hereunder includes the furnishing of all labor, material, transportation, tools, supplies, plant, equipment and appurtenances, unless hereinafter specifically excepted, necessary for the complete and satisfactory construction, disinfection and testing of the proposed water supply well described under Sec. 1–1.7.

Sec. 1–1.2—Permits, Certificates, Laws and Ordinances

The contractor shall, at his own expense, procure all permits, certificates and licenses required of him by law for the execution of his work. He shall comply with all federal, state or local laws, ordinances or rules and regulations relating to the performance of the work.

Sec. 1–1.3—Location

The well to be constructed hereunder is to be located at (Definite location to be inserted here together with reference to accompanying plans, if any.).

Sec. 1–1.4—Local Conditions (see Sec. A1–3 in Appendix)

(Insert here information regarding test wells, existing nearby wells, availability of power, unusual conditions affecting work, etc., such information to be in the form of log of test well, geologist's report, plans, etc.). This information regarding sub-surface conditions is intended to assist the contractor in preparing his bid. However, the owner does not guarantee its accuracy, nor that it is necessarily indicative of conditions to be encountered in sinking the well to be constructed hereunder, and the contractor shall satisfy himself regarding all local conditions affecting his work by personal investigation and neither the information contained in this section nor that derived from maps or plans, or from the owner or his agents or employees shall act to relieve the contractor from

any responsibility hereunder or from fulfilling any and all of the terms and requirements of his contract.

Sec. 1-1.5—Boundaries of Work

The owner shall provide land or rights-of-way for the work specified in this contract and make suitable provisions for ingress and egress, and the contractor shall not enter on or occupy with men, tools, equipment or material, any ground outside the property of the owner without the written consent of the owner of such ground. Other contractors and employees or agents of the owner may for all necessary purposes enter upon the work and premises used by the contractor, and the contractor shall conduct his work so as not to impede unnecessarily any work being done by others on or adjacent to the site.

Sec. 1-1.6—Protection of Site

Excepting as otherwise provided herein, the contractor shall protect all structures, walks, pipelines, trees, shrubbery, lawns, etc., during the progress of his work; shall remove from the site all cuttings, drillings, debris and unused materials; and shall, upon completion of the work, restore the site as nearly as possible to its original condition, including the replacement, at the contractor's sole expense, of any facility or landscaping which has been damaged beyond restoration to its original condition or destroyed. Water pumped from the well shall be conducted to a place where it will be possible to dispose of the water without damage to property or the creation of a nuisance. (Name "a place" definitely, if possible.)

Sec. 1-1.7—General Description of Well (see Sec. A1-4 in Appendix)

The completed well is to consist of the following principal items: (Insert here information pertaining to size, depth, screen, etc.).

Sec. 1-1.8—Facilities or Material To Be Furnished by Owner

The owner shall furnish to the contractor at the site of the work free of cost the following: (Insert here any services or material to be furnished by owner, such as casing, screen, power, water, transportation, etc.).

Sec. 1-1.9—Competent Workmen

The contractor shall employ only competent workmen for the execution of his work and all such work shall be performed under the direct supervision of an experienced well driller satisfactory to the engineer.

Section 1-2—Casings and Well Screens

Sec. 1-2.1—Casings (see Sec. A1-5 in Appendix)

Casings to be used hereunder as a part of the permanent well shall be of new (material) having the following minimum weights and dimensions: .... id. (od.) casing .... lb. per lin. ft., ... in. id. (od.) casing .... lb. per lin. ft. (*List all sizes and weights.*) Casing shall be provided with drive shoes of approved type. (*Drive shoes optional.*) Casings shall have screwed (welded) joints.

Sec. 1–2.2—Well Screens (Unconsolidated Formations Only *) (see Sec. A1–6 in Appendix)

2.2.1—Diameter and Length

The screen to be furnished and installed hereunder shall have a minimum nominal diameter of .... in. and a minimum length of active screen of .... ft.

2.2.2—Material

The screen shall be constructed entirely of (Monel metal) (super-nickel) (Everdur metal) (silicon bronze) (silicon red brass) (red brass) (stainless steel) (Toncan iron) (Armco iron) (steel).

2.2.3—Type

The screen shall be of the (perforated tube) (non-continuous slot) (continuous slot) (shutter) (bar) (wire-wound) type.

2.2.4—Openings

Screen openings shall be .... in. in width at their narrowest point. The number and area of openings shall be such that the expected yield of the well may be developed with a minimum loss of head. (*Alternate:* The size of openings shall be determined in accordance with the effective size and uniformity coefficient of the sands found in the water-bearing strata.)

* Although screens are sometimes placed in rock wells, these specifications assume that they will be used in unconsolidated formations only.

The shape of openings or slots shall be so designed as to prevent clogging and shall be free from jagged edges, irregularities, etc., that will accelerate clogging or corrosion.

2.2.5—Strength

The screen shall have adequate strength to resist the external forces that will be applied after it is installed and to minimize the likelihood of damage during the installation. The screen must have no change of alignment at any of its joints after installation. If required by the engineer, the contractor shall submit for approval drawings and other information showing the design and method of construction of the screen.

2.2.6—Fittings

The screen shall be provided with such fittings as are necessary to seal tightly the top to the casing and to close the bottom. If the screen is installed inside the casings a lead packer seal shall be used at the top which shall be so located that there is at least a 24-in. overlap of the well casing and screen. If the screen is attached to the casing a suitable coupling shall be provided or the screen shall be welded to the casing. All fittings except plugs and seals and including couplings, where required for joining sections of the screen, shall be constructed of the same material as the screen. Sections of casing over 5 ft. in length used to connect sections of screen shall not be considered as fittings.

Section 1–3—Description of Work

(See Section A1–4 in Appendix)

Section 1-4—Testing for Yield and Drawdown

(See Section A1-7 in Appendix)

Sec. 1-4.1—Time of Test

After the well has been completely constructed and cleaned out and the depth of the well accurately measured, the contractor shall notify the engineer to that effect and shall make the necessary arrangements for conducting a final pumping test. Besides this final test the engineer may order the contractor to make such additional pumping tests during and after construction as he deems necessary. All tests shall be run with similar equipment and in a like manner to that hereinafter described.

Sec. 1-4.2—Test Pump

The contractor shall furnish and install necessary pumping equipment capable of pumping to the required point of discharge a maximum of at least .... gpm. (see Sec. A1-7.2) with the pumping level .... ft. (see Sec. A1-7.3) below ground but with satisfactory throttling devices, so that the discharge may be reduced to .... gpm. (see Sec. A1-7.4).

The pumping unit shall be complete with prime mover of ample power, controls and appurtenances and shall be capable of being operated without interruption for a period of .... hours (see Sec. A1-7.5).

Sec. 1-4.3—Auxiliary Equipment

The contractor shall furnish all necessary discharge piping for the pumping unit, which shall be of sufficient size and length to conduct the water being pumped a distance of .... ft. (see Sec. A1-7.6) from the well. He shall also furnish, install and maintain equipment of approved size and type for measuring the flow of water; such equipment to be a weir box, orifice or water meter. To measure the elevation of the water level in the well, an air line complete with gage, hand pump and check valve shall be provided. Unless otherwise permitted, the air line shall be securely fastened to the pumping unit and shall terminate approximately at the maximum desired pumping level stated in Sec. 1-4.2 but shall in no case be nearer than 2 ft. to the end of the suction pipe.

Sec. 1-4.4—Duration of Test

Except as otherwise provided, the contractor shall furnish all labor, motive power, lubricating oil and other necessary materials, equipment, labor and supplies required and shall operate the pumping unit at such rates of discharge and for such periods of time as directed, excepting that the final test shall be run for a period of .... hours (see Sec. A1-7.7). Accidental interruptions may, if so agreed upon between the contractor and the engineer, be compensated for by correspondingly extending the time of the completion of the test run. After the completion of the final test the contractor shall remove by bailing, sand pumping or other methods any sand, stones or other foreign material that may have become deposited in the well. Time stated for the duration of the final test is a minimum only and the engineer reserves the right to require the contractor to extend such period of test, or to make additional tests.

(NOTE: *See Sec. A1-7.9 for special clause for guaranteed wells.*)

Section 1-5—Grouting and Sealing

(See Section A1-8 in Appendix)

Sec. 1-5.1—Grouting Material

The annular space between the inner or protective casing and the outer casing or hole shall be filled with cement grout. Grout shall be proportioned of cement and the minimum quantity of water (not over 6 gal. per cu.ft. of cement) required to give a mixture of such consistency that it can be forced through the grout pipes. The mixture, method of mixing and consistency of grout shall be approved by the engineer.

(NOTE: *In some cases, particularly in gravel wall wells, annular space is not grouted. See Appendix A1-4.*)

Sec. 1-5.2—Placement of Grout

Before proceeding with the placing of the grout the contractor shall secure the engineer's approval of the method he proposes to use. No method will be approved that does not specify the forcing of grout from the bottom of the space to be grouted towards the surface. A suitable cement retainer, packer or plug shall be provided at the bottom of the inner casing so that grout will not leak through into the bottom of the well. The grouting shall be done continuously and in such a manner as will insure the entire filling of the annular space in one operation. No drilling operations or other work in the well will be permitted within 72 hours after the grouting of casings. If quick-setting cement is used this period may be reduced to 24 hours.

Sec. 1-5.3—Grouting Liners

Where required by the engineer, liners shall be grouted. The method to be used shall be detailed by the contractor for the approval of the engineer.

Section 1-6—Testing for Plumbness and Alignment

(See Section A1-9 in Appendix)

Sec. 1-6.1—Requirement to Test

All holes shall be constructed and all casing and liners set round, plumb and true to line as defined herein. To demonstrate the compliance of his work with this requirement the contractor shall furnish all labor, tools and equipment and shall make the tests described herein in the manner prescribed by, and to the satisfaction of, the engineer. Tests for plumbness and alignment must be made after the complete construction of the well and before its acceptance. Additional tests, however, may be made by the contractor during the performance of the work. No specific payments shall be made by the owner for making these tests.

Sec. 1-6.2—Description of Test

Plumbness and alignment shall be tested by lowering into the well to a depth of .... ft. (*lowest anticipated pump setting*) a section of pipe 40 ft. long or a dummy of the same length. The outer diameter of the plumb shall not be more than ½ in. smaller than the diameter of that part of the casing or hole being tested. If a dummy is used it shall consist of a rigid spindle with three rings, each ring being 12 in. wide. The rings shall be truly cylindrical and

shall be spaced one at each end of the dummy and one ring in the center thereof. The central member of the dummy shall be rigid so that it will maintain the alignment of the axes of the rings.

Sec. 1-6.3—Requirements for Plumbness and Alignment

Should the dummy fail to move freely throughout the length of the casing or hole to a depth of .... ft. (*lowest anticipated pump setting*) or should the well vary from the vertical in excess of two-thirds the smallest inside diameter of that part of the well being tested per 100 ft. of depth, or beyond limitations of this test, the plumbness and alignment of the well shall be corrected by the contractor at his own expense and, should he fail to correct such faulty alignment or plumbness, the engineer may refuse to accept the well. The engineer may waive the requirements of this paragraph for plumbness if, in his judgment, (a) the contractor has exercised all possible care in constructing the well and the defect is due to circumstances beyond his control; (b) the utility of the completed well will not be materially affected; (c) the cost of necessary remedial measures will be excessive. In no event will the provisions of this paragraph with respect to alignment be waived.

Section 1-7—Disinfection

(See Section A1-10 in Appendix)

Sec. 1-7.1—Time of Disinfection

After the well has been completely constructed, it shall be thoroughly cleaned of all foreign substances, including tools, timbers, rope, debris of any kind, cement, oil, grease, joint dope and scum. The casing pipe shall be thoroughly swabbed, using alkalis if necessary, to remove oil, grease or joint dope. The well shall then be disinfected with a chlorine solution.

Sec. 1-7.2—Chlorine Solution

The chlorine solution used for disinfecting the well shall be of such volume and strength and shall be so applied that a concentration of at least 50 ppm. of chlorine shall be obtained in all parts of the well. Chlorine solution shall be prepared and applied in accordance with the directions of, and to the satisfaction of, the engineer, and shall remain in the well for a period of at least two hours.

Sec. 1-7.3—Requirements for Disinfection of Test Pump

In the event that the test pump is installed after the well has been disinfected, all exterior parts of the test pump coming in contact with the water shall be dusted with a chlorine compound as directed by the engineer.

Section 1-8—Samples and Records

Sec. 1-8.1—Samples of Formations

The contractor shall keep an accurate record of the location of the top and bottom of each stratum penetrated and shall save and deliver to the engineer a sample of material taken from each 5 (10) (20) ft. of drilling and at every change of formation.

Sec. 1–8.2—Record of Casing Pipe

The contractor shall keep an accurate record as assembled of the order, number, size and lengths of the individual pieces of pipe installed in the well.

Sec. 1–8.3—Liquidated Damages (Optional)

Failure on the part of the contractor to obtain, preserve and deliver such samples or records to the engineer shall be considered an actual damage to the owner and shall authorize the owner to retain from moneys due or to become due the contract the sum of .... dollars as liquidated damages for each sample that the contractor shall fail to obtain, preserve and deliver, or for each length of pipe not properly measured and recorded in the order in which it was placed in the well. In the event that, in the opinion of the engineer, the failure of the contractor to take and preserve the samples may affect the proper design of the screen, the contractor may be required to perform such work as the engineer deems necessary to remedy such failure. (*Last sentence relates to unconsolidated formations only.*)

Sec. 1–8.4—Daily Reports

The contractor shall also submit a daily report describing the nature of material encountered, the work done during each day, including the items of work accomplished, such as depth drilled, casing set, etc., the water level in the well at the beginning and end of each shift and such other pertinent data as he is requested to make a record of by the engineer.

Section 1–9—Protection of Quality of Water

(See Section A1–11 in Appendix)

Sec. 1–9.1—Precautions To Be Taken

The contractor shall take such precautions as are necessary or as may be required permanently to prevent contaminated water or water having undesirable physical or chemical characteristics from entering, through the opening made by the contractor in drilling the well, the stratum from which the well is to draw its supply. He shall also take all necessary precautions during the construction period to prevent contaminated water, gasoline, etc., from entering the well either through the opening or by seepage through the ground surface.

Sec. 1–9.2—Corrective Work

In the event that the well becomes contaminated or that water having undesirable physical or chemical characteristics does enter the well due to the neglect of the contractor, he shall, at his own expense, perform such work or supply such casings, seals, sterilizing agents or other material as may be necessary to eliminate the contamination or shut off the undesirable water.

Sec. 1–9.3—Freedom From Sand and Turbidity

The contractor shall exercise extreme care in the performance of his work in order to prevent the breakdown or caving in of strata overlying that from which the water is to be drawn. He shall develop, pump or bail the well by such methods as may be approved by the engineer until the water pumped from the well shall be

substantially free from sand and until the turbidity is less than 5 on the silica scale described in *Standard Methods of Water Analysis*.

(NOTE: *The above paragraph is satisfactory in most instances. Occasionally a correctly constructed well will be encountered that will not clear up despite the best efforts of the contractor. In such instances it is suggested that the requirements relative to quality of water, contained in the last sentence, be waived.*)

Section 1-10—Temporary Capping

At all times during the progress of the work, the contractor shall protect the well in such manner as effectively to prevent either tampering with the well or the entrance of foreign matter into it, and, upon its completion, he shall provide and set a substantial screwed, flanged or welded cap satisfactory to the engineer.

Section 1-11—Abandonment of Well

In the event that the contractor shall fail to sink the well to the depth specified or to such lesser depth as ordered by the engineer, or should he abandon the well because of loss of tools or for any other cause, he shall, if requested and as directed by the engineer, fill the abandoned hole with clay or clay and concrete and remove the casing. Salvaged material furnished by the contractor shall remain his property.

Section 1-12—Measurement and Compensation

(See Section A1-2 in Appendix)

APPENDIX

Section A1-1—Forms of Proposal

Sec. A1-1.1—General

This appendix sets forth suggested forms of proposal to be inserted in the contract documents ahead of "Contract" and after "Notice to Bidders."

Sec. A1-1.2—Advantages Derived From Carefully Drawn Proposal Forms

The aim of these specifications is to assist the purchaser in procuring the best possible well at a fair and reasonable cost. One of the surest ways of attaining this aim is to secure the services of an experienced and responsible contractor but, unfortunately, in the case of most municipal contracts the work must be awarded to the lowest bidder. It is true that the law generally permits an award to the lowest "responsible" bidder but it is usually hard to disqualify an undesirable bidder on that ground. Where specifications are sketchy, indefinite or unduly restrictive, the less reliable contractor is favored over his more responsible competitor who must include in his bid an allowance for contingencies, must avoid unbalancing his bid and refuse to take a chance that a major portion of his compensation will result from extra work claims. The possibilities of securing the desirable contractor can be increased by using proposal forms that will protect him to the fullest extent practicable against the possibility that unforeseen circumstances may increase his costs without adequate compensation.

Sec. A1-1.3—Three Types of Proposal Forms

There are three methods of securing bids for wells that are in general use. These are the unit price, the lump sum and the guaranteed yield methods. Sometimes two or even all three of these methods are combined. Legal restrictions may occasionally dictate the choice of method.

1.3.1—*Advantages of Unit Price Method*

The unit price method of obtaining bids is the most satisfactory when there is doubt as to the nature of the underground conditions to be encountered and the exact size, depth and type of construction of the proposed well. It is more difficult to prepare contract documents using this method. The unit price proposal form must be carefully prepared to provide for possible contingencies and to prevent the submission of unbalanced bids.

1.3.2—*Advantages of Lump Sum Method*

The lump sum method of securing bids is perhaps the best when all conditions are known in advance, such as the depth and size of well, length of casing and probable yield. It is an unsatisfactory method, however, if there is doubt concerning exactly what the finished well will consist of, because, if changes become necessary, such changes can only be made with the consent of both parties and the

additions to or deductions from the contractor's bid price are generally a matter of considerable dispute.

1.3.3—*Advantages of Guaranteed Yield Method*

The guaranteed yield method has a very definite place, particularly when the owner is unwilling to proceed with the construction of the well unless he is sure that the desired water will be obtained, even though he knows that the well purchased by this method may cost him more. It is also of value where the formation must be developed and where the exact method and extent of such development cannot be determined accurately in advance.

Sec. A1-1.4—Proposal Form—Unit Price Method

The following schedule of items is suggested for obtaining bids on wells on a unit price basis. Certain items listed hereunder should be omitted for some wells and, under unusual conditions, other items should be added.

1.4.1—*Consolidated Formations*

Item 1—For setting up and removing equipment, the lump sum of .... dollars and .... cents ($........).

(NOTE: *To prevent unbalancing, it is desirable that the engineer fix this price in advance.*)

Item 2—For drilling, casing and sealing approximately .... ft. of ....-in. hole, including any necessary couplings and shoes, the sum of .... dollars and .... cents ($........) per lin.ft.

(NOTE: *Ask for separate prices for specific sizes of cased hole, denoting them as Items A, B, C, etc.*)

Item 3—For drilling approximately ....ft. of ....-in. uncased hole, the sum of .... dollars and .... cents ($........) per lin.ft.

(NOTE: *Ask for separate prices for specific sizes of uncased hole, denoting them as Items A, B, C, etc.*)

Item 4—For grouting approximately .... lin.ft. of annular space between ....-in. inner casing and outer casing or hole, the sum of .... dollars and .... cents ($........) per bag of cement.

Item 5—For furnishing and placing approximately .... ft. of ....-in. liners, the sum of .... dollars and .... cents ($........) per lin.ft.

(NOTE: *Item 5 is usually not-required.*)

Item 6—For reaming or underreaming approximately .... ft. of ....-in. hole to ....-in. hole, the sum of .... dollars and .... cents ($........) per lin.ft.

(NOTE: *Item 6 is usually not required.*)

Item 7—For testing for yield and drawdown for approximately .... hours, the sum of .... dollars and .... cents ($........) per hour.

Item 8—For miscellaneous work and material, the lump sum of .... dollars and .... cents ($........).

1.4.2—*Unconsolidated Formations*

Item 1—For setting up and removing equipment, the lump sum of .... dollars and .... cents ($........).

Item 2—For drilling, casing and sealing approximately .... ft. of ....-in. hole, including any necessary couplings and shoes, the sum of .... dollars and .... cents ($........).

(NOTE: *Ask for separate prices for specific sizes of cased hole, denoting them as Items A, B, C, etc.*)

Item 3—For grouting approximately .... lin.ft. of annular space

between ....-in. inner casing and outer casing or hole, the sum of .... dollars and .... cents ($..........) per bag of cement.

Item 4—For furnishing and placing approximately .... ft. of ....-in. well screen, the sum of .... dollars and ....cents ($..........) per ft.

Item 5—For developing well, the lump sum of .... dollars and .... cents ($..........).

Alternate

For furnishing necessary equipment and services of .... men for approximately .... hours for developing well, the sum of .... dollars and .... cents ($..........) per hour.

Item 6—For testing for yield and drawdown for approximately .... hours, the sum of .... dollars and .... cents ($..........) per hour.

Item 7—For miscellaneous work and material, the lump sum of .... dollars and .... cents ($..........).

Sec. A1-1.5—Proposal Form—Lump Sum Method

When a well is to be purchased on a lump sum basis, it is suggested that the following paragraph be used:

Item 1—For furnishing all labor, materials, tools and equipment, and for constructing, finishing and testing complete in accordance with the attached contract, specifications and drawings the well therein described, the lump sum of .... dollars and .... cents ($..........).

When using this method of obtaining bids, it is wise to make provision for changes that may either increase or decrease the amount of work to be done. This may be accomplished by either asking for bids on, or by fixing unit prices for, certain items where it is anticipated that there may be changes; or by stating that additional work, if required, will be paid for under the "extra work" clause of the contract. The contract, in any event, should contain an extra work clause because no matter how carefully the specifications are drawn, certain additional work may become necessary that cannot be anticipated.

Unit prices covering changes on a lump sum job may be obtained by inserting a paragraph similar to the following:

> In the event that additions to or deductions from the work shown on the plan or described in the specifications are made, the bidder agrees that the following unit prices shall be used in making additions to or deductions from the contract amount.

There should then be set forth, with blanks to be filled in by the bidder, the various items for which supplementary prices are to be fixed, such as additional length of casing, hole or screen.

To provide for changes by fixing unit prices, the following paragraph should be inserted:

> In the event that additions to or deductions from the work shown on the plans or described in the specifications are made, and that they are covered by the following items, the bidder agrees that the following unit prices shall be used in making additions to or deductions from the contract amount.

There should then be listed the various items together with the fixed supplemental prices.

The fixing of prices for additions or deductions should be resorted to only if it is anticipated that the changes to be made will be minor, because otherwise the contractor may claim that the allowances stated are insufficient to recompense him for the additional work

or that they penalize him too greatly by omitting certain portions.

Whereas additional work may be paid for under the extra work clause of the contract (generally cost plus 15 per cent), this method of providing for changes should be used as sparingly as possible because it is liable to lead to disputes regarding the value of additional material furnished and the time of and rates for labor and equipment used.

Sec. A1-1.6—Proposal Form—Guaranteed Yield Method

When a well is to be purchased on a guaranteed yield basis, it is important that the specifications cover the minimum construction standards, and the method and duration of test, as well as the maximum and minimum amount of water to be paid for. It is frequently advisable to ask for an additional price per hour for extending the period of test. The following proposal form is suggested:

Item 1—For furnishing all labor, materials, tools and equipment, and for constructing, finishing, testing and guaranteeing complete, the well to yield under the conditions of test described herein, in accordance with the attached contract, specifications and drawings, a minimum of .... gpm., the lump sum of .... dollars and .... cents ($..........).

Item 2—For each additional gallon per minute of water furnished by the well constructed under Item 1 beyond the minimum yield of .... gpm., the sum of .... dollars and .... cents ($..........) per gal.

Item 3—For additional testing beyond that called for under Item 1, if ordered by the engineer, the sum of .... dollars and .... cents ($..........) per hour.

Bids will be compared by adding to the total bid for Item 1 the unit price for Item 2 multiplied by .... gpm. and the unit price bid for Item 3 multiplied by .... hours.

Section A1-2—Form of Measurement and Compensation Clauses

(See Section 1-12 of Specifications)

Sec. A1-2.1—Position in Specifications

Measurement and compensation clauses are sometimes made a part of the proposal, are sometimes incorporated in the body of the specifications where they are combined with a description of the work to be done under the particular item, and are sometimes placed at the end of the specifications. In this appendix the measurement and compensation clauses have been written for insertion at the end of the specifications, but they may be incorporated elsewhere if desired.

Sec. A1-2.2—Form for Use With Unit Price Method

The following paragraphs are suggested for inclusion in the specifications where bids are secured by the unit price method. Naturally, paragraphs covering items not used in the proposal should be omitted.

2.2.1—*Consolidated Formations*

Item 1—Setting Up and Removing Equipment. Under this item the contractor shall be paid the price bid (fixed) in the proposal as full compensation for bringing his equipment

to the job and setting up and removing same.

Item 2—Drilling, Casing and Sealing ....-In. Hole. (Different sizes of cased holes should be denoted as Items A, B, C, etc.) There are included under this item the costs of the casing pipe and of all drive shoes, couplings, fittings, seals, etc. The cased hole shall be measured for payment as the vertical distance between such limits as the hole is directed to be, and actually is, constructed.

Item 3—Drilling ....-In. Uncased Hole. (Different sizes of uncased holes should be denoted as Items A, B, C, etc.) Under this item the contractor shall be paid the unit price bid in the proposal as full compensation for drilling and finishing complete the uncased hole of the diameter listed. The uncased hole shall be measured for payment as the vertical distance between such limits as the hole is directed to be, and actually is, drilled.

Item 4—Grouting Annular Space Between ....-In. Casing and ....-In. Casing or Hole. Under this item the contractor shall be paid the unit price per bag of cement bid in the proposal for furnishing and placing grout in the annular space between the ....-in. casing and ....-in. outer casing or hole. Measurement shall be made of the actual number of 94-lb. bags of cement used for grouting the annular space where and as directed.

Item 5—Furnishing and Placing ....-In Liner. Under this item the contractor shall be paid the unit price bid in the proposal for placing ....-in. liner in the ....-in. hole where and if directed to do so by the engineer. This item shall cover the furnishing of the casing and seals and the accurate centering of same, and also the grouting of the liner, if required, except that cement shall be paid for under Item 4. Payment shall be in addition to that allowed for under the items for drilling the uncased hole. Measurement shall be made for the actual length of liner placed where directed.

Item 6—Reaming or Under-Reaming ....-In. Hole to ....-In. Hole. Under this item the contractor shall be paid the price bid in the proposal for reaming or under-reaming ....-in. hole to ....-in. hole. Payment allowed hereunder shall be in addition to that allowed under the item covering the drilling of the original uncased hole. Casings or liners, if required, shall be furnished and placed in the enlarged hole under this item, but in such event the contractor shall be allowed the actual cost of such material as is incorporated into the well plus 15 per cent. Measurement shall be made for the actual length of hole reamed or under-reamed as directed.

Item 7—Testing for Yield and Drawdown. Under this item the contractor shall be paid the unit price bid in the proposal for making the required tests for yield and drawdown. Tests shall be made with equipment previously described herein and for such periods as may be directed by the engineer. Allowance shall be made up to a maximum of (*) hours for the actual time necessary to install and place the pump in operation and an additional allowance shall be made up to a maximum of (*) hours for the time necessary for removing the test pump. Except for these two allowances, payment under this item shall only be made for the actual length of time the pump is in operation and deductions shall be made for all breakdowns or stops or for

* Depends on depth of well, size of pump, etc. Usually 4 to 8 hours. Consult local driller.

such tests as are not made in complete accordance with the specifications. No payment shall be made hereunder for tests made by the contractor for his own information or for pumping to develop the well.

Item 8—Miscellaneous Work and Material. Under this item the contractor shall be paid the lump sum bid in the proposal as full compensation for (Insert here special work, if any, such as capping of wells, water analyses, test wells, etc.).

2.2.2—Unconsolidated Formations

Item 1—Setting Up and Removing Equipment. Under this item the contractor shall be paid the price bid (fixed) in the proposal as full compensation for bringing his equipment to the job and setting up and removing same.

Item 2—Drilling, Casing and Sealing ....-In. Hole. (Different sizes of cased holes should be denoted as Items A, B, C, etc.) Under this item the contractor will be paid the unit price bid in the proposal as full compensation for drilling, casing and sealing complete the cased hole of the diameter listed. There are included under this item the costs of the casing pipe and of all drive shoes, couplings, fittings, seals, etc. Cased hole shall be measured for payment as the vertical distance between such limits as the hole is directed to be, and actually is, constructed.

Item 3—Grouting Annular Space Between ....-In. Casing and ....-In. Casing or Hole. Under this item the contractor shall be paid the unit price per bag of cement bid in the proposal for furnishing and placing grout in the annular space between the ....-in. casing and the ....-in. outer casing or hole. Measurement shall be made of the actual number of 94-lb. bags of cement used for grouting the annular space where and as directed.

Item 4—Furnishing and Placing ....-In. Well Screen. Under this item the contractor shall be paid the price bid in the proposal for furnishing the screen described in the specifications complete with necessary end fittings and seals. Length of screen paid for shall be the length actually installed in accordance with the directions of the engineer.

Item 5—Developing Well. Under this item the contractor shall be paid the lump sum (unit price per hour) bid in the proposal for developing the well. Included hereunder is the furnishing of the necessary material and equipment, including well rigs, pumps, air compressors, piping, gravel,* wash lines, etc., and all necessary labor, power and water for agitating the formation and removing therefrom fine sand, clay or other undesirable materials and adding gravel of the desired size and quality.* The number of hours paid for shall be the number of hours during which the contractor is actually engaged on the site in developing the well in accordance with the direction of the engineer.†

Item 6—Testing for Yield and Drawdown. Under this item the contractor shall be paid the unit price bid in the proposal for making the required tests for yield and drawdown. Tests shall be made with equipment previously described herein and for such periods as directed by the engineer. Allowance shall be made up to a maximum of

* Use for gravel-packed wells only.

† Omit this sentence if lump sum bid for this item is secured.

(‡) hours for the actual time necessary to install and place the pump in operation and an additional allowance shall be made up to a maximum of (‡) hours for the time necessary for removing the test pump. Except for these two allowances, payment under this item will only be made for the actual length of time the pump is in operation and deductions shall be made for all breakdowns or stops or for such tests as are not made in complete accordance with the specifications. No payment will be made hereunder for tests made by the contractor for his own information or for pumping to develop the well.

Item 7—Miscellaneous Work and Material. Under this item the contractor shall be paid the lump sum bid in the proposal as full compensation for (Insert here special work, if any, such as capping of wells, water analyses, test wells, etc.).

Sec. A1-2.3—Form for Use With Lump Sum Method

When the lump sum method of obtaining bids is used without supplementary prices, it is not necessary to have special measurement and payment clauses beyond those usually contained in the body of the contract. If, however, supplementary prices are included, either as bids from the contractor or as fixed by the engineer, additional clauses are necessary and may be inserted either at the end of the specifications or in the contract. The following form is suggested for use in addition to the general payment clause covering the lump sum:

Should the amount of work to be done under this contract vary from that shown on the plans or described in the contract documents, an addition to or deduction from the lump sum bid under Item 1 will be made at the unit prices bid (fixed) for such variations in the quantities in accordance with the following items: (Add various items using set-up given in this appendix under "Unit Price Method" for guide.).

Sec. A1-2.4—Form for Use With Guaranteed Yield Method

The following paragraphs are suggested for inclusion in the specifications where bids are secured by using the guaranteed yield method:

Item 1—Constructing, Finishing, Testing and Guaranteeing a Well Having a Minimum Yield of .... gpm. Under this item, provided the contractor is successful in furnishing the required quantity of water and otherwise meets the requirements of the specifications concerning quality, minimum construction standards, test, etc., the contractor shall be paid the lump sum bid hereunder. No payment shall be made under this or any other item if the contractor is unsuccessful in obtaining the minimum required yield.

Item 2—For Each Additional Gallon per Minute Water Furnished by a Well Constructed Under Item 1 Above Specified Minimum. Under this item the contractor shall be allowed additional compensation for the well constructed under Item 1 provided he is successful in developing more water than the .... gpm. called for under that item. The quantity of water paid for hereunder will be obtained by deducting from the total yield the minimum quantity as called for under Item 1 except that the maximum quantity

‡ Depends on depth of well, size of pump, etc. Usually 4 to 8 hours. Consult local driller.

of water to be paid for under this item is .... gpm. Water paid for under this item is subject to the same conditions regarding test and guarantee as called for under Item 1.

Item 3—For Additional Testing. Under this item the contractor shall be paid the unit price per hour bid in the proposal for making additional tests to determine yield and drawdown or for extending the period of tests specified in the contract. Tests shall be made with equipment previously described herein and for such periods as directed by the engineer. Except where tests called for elsewhere are extended, allowance will be made up to a maximum of .... hours for the actual time necessary to install and place the pump in operation and additional allowance shall be made up to a maximum of .... hours for the time necessary for removing the test pump. Except for these two allowances, payment under this item shall only be made for the actual length of time the pump is in operation and deductions shall be made for all breakdowns or stops or for such tests as are not made in complete accordance with the specifications.

Section A1-3—Information Relative to Local Conditions

(See Section 1–1.4 in Specifications)

Sec. A1-3.1—Purpose of Furnishing Information

In order to enable the contractor to formulate an intelligent bid, he should be given such reliable information as is available regarding local conditions affecting his work. Unreliable information or information based on hearsay should not be inserted in the contract documents because the owner may become liable for damages in the event it proves faulty.

Sec. A1-3.2—Type of Information To Be Furnished

The following paragraphs give examples of the type of information which may be furnished to prospective bidders:

EXAMPLE A

There is located approximately .... ft. from the well to be constructed hereunder a well owned by .... This well is .... ft. deep. The upper .... ft. are cased with ....-in. pipe, the next .... ft. with ....-in. pipe and the lower .... ft. are (........-in. uncased hole) (........-in. screen). The yield of this well is reputed to be approximately .... gpm. The static water level varies between .... ft. and .... ft. below ground level and the water level when pumping at .... gpm. varies between .... ft. and .... ft.

EXAMPLE B

A test well was installed by .... Company in 19.... at a point .... ft. from the proposed location of the well to be installed hereunder. There is available at the office of the owner the following information obtained from the sinking of said test well. (List here available information such as the following:)

A geologist's report made by ....

A driller's log of the test well.

Samples of the information encountered, which samples were taken by .... Company, the contractor who drilled this test well.

(NOTE: *The geologist's report or driller's log may be inserted in the specifications if preferred.*)

Section A1-4—Description of Work

(See Sections 1-1.7 and 1-3 in Specifications)

Sec. A1-4.1—General

This section sets forth points to be considered in designing and writing a description of the well. It should be the purpose of the specifications to describe to the contractor the completed well but not to restrict the contractor regarding methods that should be used in constructing the well except where the quantity or quality of the water produced or the well's structural stability may be affected. Such exceptions are covered generally in other sections of the Appendix. The applicable rules of the state health department or other regulatory body should be studied and given due force.

Notwithstanding that distance from source of pollution must continue to be an important consideration in the development of safe ground water supplies, particularly from shallow water-bearing formations, the establishment of an arbitrary minimum distance is not a satisfactory solution of the problem of well sanitation. Although a 50-ft. minimum distance from a source of pollution may be an adequate safeguard in unconsolidated or fine-grained rock formations, several hundred feet may be inadequate in coarse-grained materials and several thousand feet in creviced rock formations. Similarly, the establishment of an arbitrary minimum casing depth cannot logically be supported.

In the development of a ground water supply, therefore, the type of construction to be utilized should be based, first, on the depth to available water-bearing zones and the type of formations penetrated, and, second, on the proximity of existing or possible future sources of pollution, due regard being given to a reasonable factor of safety. Thus, if two water-bearing formations are available at different depths, and the upper is subject to possible pollution and the lower is adequately safeguarded by natural conditions, the well construction should be such as to case off the upper and to develop the lower formation. If only one water-bearing formation at a shallow depth is available, not only should the construction be such that it will maintain or improve the natural protective conditions, but the well should be located in a relatively isolated area subject to complete control by the owner.

Sec. A1-4.2—Type of Information To Be Furnished

The contractor should be advised regarding the number of wells to be constructed, the minimum diameter of the wells, their estimated depth by sizes of casing or hole, any unusual construction features, the finishing of the well at the top, and the location of the place to which water pumped from the well may be discharged. In the event that the well is to be purchased on the guaranteed basis the quantity of water desired should be stated. The following examples show the type of information that should be included in the specifications under this item:

Example A—(Type No. 7)

Well in Consolidated Rock Formation

The completed well to be constructed hereunder shall be comprised of the following sections:

A first section extending to an estimated depth of 100 ft., penetrating soil

sand, clay, gravel and rock, extending from the surface of the ground into solid rock. This section is to be cased with 24-in. od. black steel pipe. If the hydraulic rotary method of construction is used this 24-in. casing may be omitted.

A second section estimated to be 100 ft. long, in rock extending from the lower end of the first section to a point approximately 200 ft. below the surface of the ground. This second section shall be drilled 23 in. in diameter and shall be cased with 18-in. od. pipe which shall extend from a point 1 ft. above the ground surface to the bottom of the 23-in. hole.

A third section estimated to be 300 ft. long, in rock extending from the bottom of the 18-in. casing to a point approximately 500 ft. below the surface of the ground. This third section shall be 16 in. in diameter and shall be uncased hole.

The annular space between the 24-in. pipe or rotary drilled hole, the 23-in. hole and the 18-in. pipe shall be filled with cement grout. The top of the 18-in. casing shall be closed with a blank flange. Water pumped from the well shall be conducted by ditch to the Black River adjoining the site.

EXAMPLE B—(TYPE NO. 2)

Wells in Unconsolidated Formation

The three wells to be constructed hereunder are each to be approximately 500 ft. deep and shall be comprised of the following principal items:

An outer casing of 16-in. od. pipe extending from the surface of the ground to such point as directed in a suitable water-bearing sand stratum.

An inner casing of 10-in. id. pipe extending from the top of the well screen to a point 1 ft. above the surface of the ground. This inner casing shall be provided with means for accurately centering it in the outer casing and shall be sealed to the well screen by a packer. The annular space between the inner and outer casings shall be filled with cement grout.

A well screen approximately 10 in. in diameter and 30 ft. long exposed in the water-bearing sand.

Water pumped from the wells shall be piped to the catch basin at the corner of Elm and Market Streets.

Sec. A1–4.3—Types of Wells

It is impossible to describe in this section all types of wells or even a majority of those in common use. It is recommended that in case of doubt the writer of well specifications contact a well driller or water works engineer experienced in well drilling to ascertain the design most successfully used in the locality. The following paragraphs describe several kinds of wells in common use. Wells having casings and screen of concrete are not described here, although this type of construction has advantages under some conditions. California stovepipe wells are not illustrated, as the use of wells of this type is confined largely to the western states. In selecting the type of well to be constructed the following principles should be borne in mind:

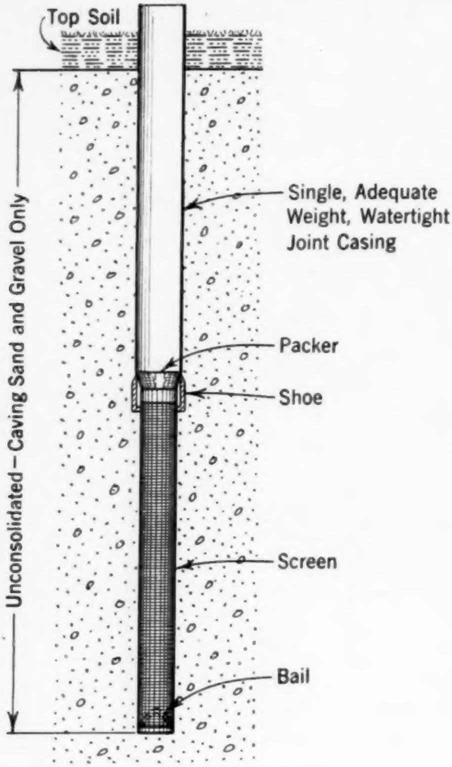
(1) The well should be so designed that it will seal off water-bearing formations that are or may be contaminated or formations that have undesirable characteristics.

(2) The well should be so designed that no opening will be formed between the ground surface and the water-bearing formation other than that through which the water is produced.

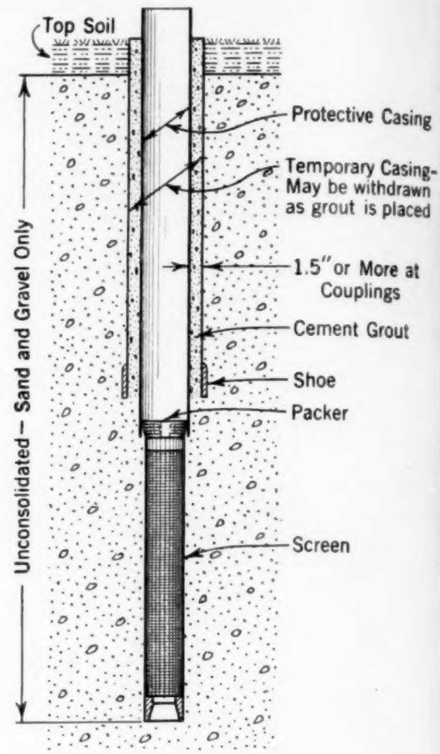
(3) The materials that are to be a part of the permanent well should be durable.

4.3.1—*Type 1—Unconsolidated Formation, Caving Material Only*

If the formations are of a caving nature for the full depth of a well,



TYPE 1
UNCONSOLIDATED FORMATION

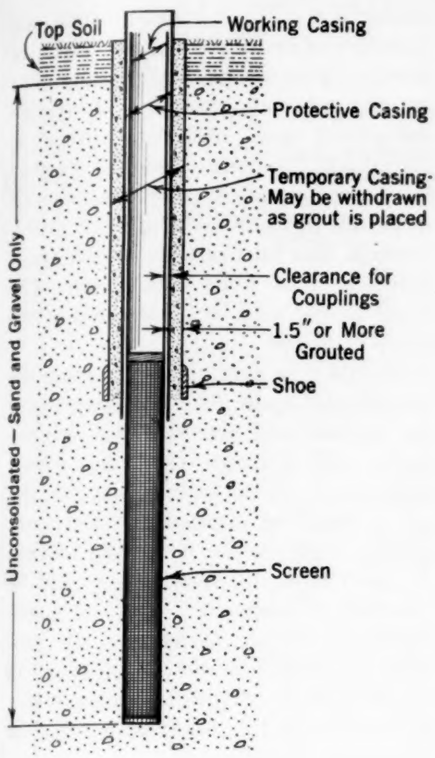


TYPE 2
UNCONSOLIDATED FORMATION

finished with a screen at the bottom, a single casing may be sufficient. It is recommended, however, that the opening made during construction outside the upper part of the casing be filled with puddled clay, cement or concrete to minimize the likelihood of surface pollution working down around the casing. In this type of construction the screen is sealed to the well casing by means of a packer and it may be replaced, if necessary.

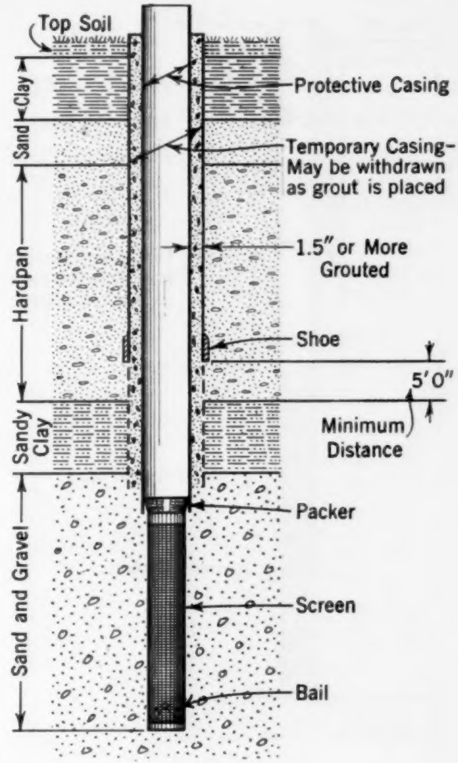
4.3.2—*Type 2—Unconsolidated Formation, Caving Material Only*

When additional protection against corrosion and pollution beyond that afforded by Type 1 is desirable, it may be provided by installing an outer casing to a sufficient depth and filling the annular space between the casings with cement grout. The screen may be placed by bailing, by jetting or by pulling back the casing to expose the screen in the water-bearing formation. The screen is independent of the casing to which it is sealed by a packer. This type of construction will permit replacement of the screen. No outer casing may be required if the hydraulic rotary method of construction is used but the diameter of the hole should be 3 to 4 in. greater than that of the couplings of the protective casing.



TYPE 3

UNCONSOLIDATED FORMATION



TYPE 4

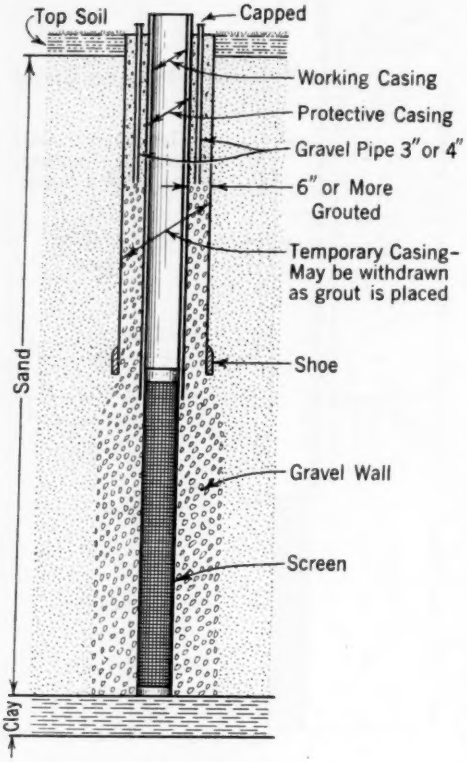
UNCONSOLIDATED FORMATION

4.3.3—*Type 3—Unconsolidated Formation, Sand and Gravel Only*

Should it be desirable to provide grout protection similar to Type 2 and also to permit removal and replacement of the screen by means of the casing to which it is attached by threaded or welded joint, the grout should be placed between two exterior casings. With such construction the intermediate casing should be considered the protective casing. The casing to which the screen is attached may be of lighter weight material than the permanent casing pipe. If the casing to which the screen is attached terminates below the surface, a suitable seal for the annular space should be placed at the top of such casing. If the well is constructed by the hydraulic rotary method, all or part of the outer casing may be eliminated.

4.3.4—*Type 4—Unconsolidated Formation, Including Clay, Hardpan or Shale*

When the water-bearing formation lies below clay, hardpan, shale or other non-caving material, the grouted type of construction should be adopted to insure sealing of the annular space formed during drilling. In such formations, if a temporary outer casing is



TYPE 5
UNCONSOLIDATED FORMATION
GRAVEL WALL

used, it should be withdrawn completely or enough so as to place the lower end within and at least 5 ft. above the bottom of the lowest stable unconsolidated formation. The grout seal should extend to the bottom of the clay or other non-caving formation and should be placed as the casing is being withdrawn. Type 3 construction is also applicable for these formations, if casing is withdrawn as indicated for Type 4. If the hydraulic rotary method of construction is used no outer casing may be required.

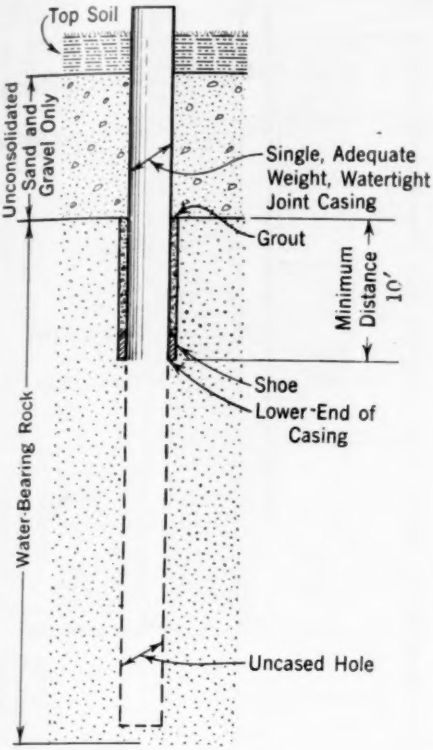
4.3.5—*Type 5—Unconsolidated Formation, Gravel Wall Wells*

This type of well may be constructed similarly to Type 3 except that the diameter of outer casing and width of annular space are usually greater. The annular space is initially used to place the gravel wall. After the gravel is placed and the development of the well has been completed, pipes are installed to permit the admission of more gravel through that part of the annular space which is to be filled with grout. The outer casing may be withdrawn as the grout is placed.

Should it be essential to maintain the full annular space for subsequent work on the well and provided the well extends only through sand and gravel formations of a caving nature, the grout could be omitted and the outer casing used as the protective casing. In such case, its thickness should be selected accordingly. In unconsolidated non-caving formations the protective casing should be encased in cement grout. If the hydraulic rotary method is used no outer casing may be required.

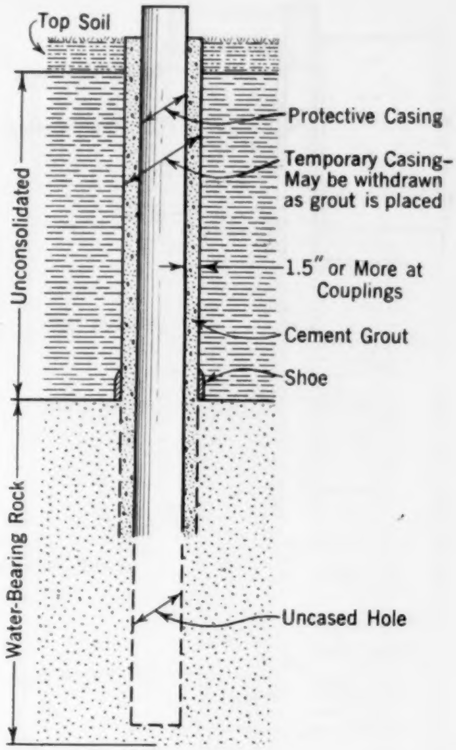
4.3.6—*Type 6—Consolidated Formation, Underlying Sand and Gravel*

The single-cased type of well penetrating rock formations is frequently used but is not recommended. Where the unconsolidated material is of a caving nature and protection against corrosion is not a factor and, further, where the mantle deposit is thick, its use can occasionally be justified on grounds of economy. It should never be used in creviced formations or where the unconsolidated material is clay, hardpan or other relatively stable material. It is extremely difficult to get a tight joint between the casing and the rock and as a result pollution or sand may enter the well. Type 7 construction is much to be preferred.



TYPE 6

CONSOLIDATED FORMATION



TYPE 7

CONSOLIDATED FORMATION

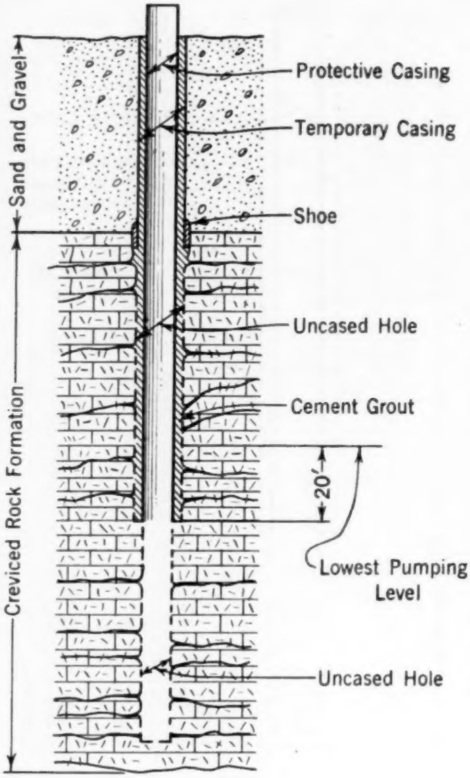
Where Type 6 construction is used, the following insert for the specifications is suggested:

The casing shall be driven to the rock formation and the drillhole extended to such depth as will provide at least 10 ft. of penetration in hard stable rock. The upper part of the hole in the rock shall be under-reamed slightly to permit the driving of the casing and shoe. The lower 10 ft. shall be under-reamed to a diameter 2 in. larger than the outside diameter of the shoe. The drillhole below the bottom of the casing shall then be filled with grout by means of a dump bailer and the casing driven to its final setting. Drilling operations shall not be resumed until 72 hours after placement of the grout.

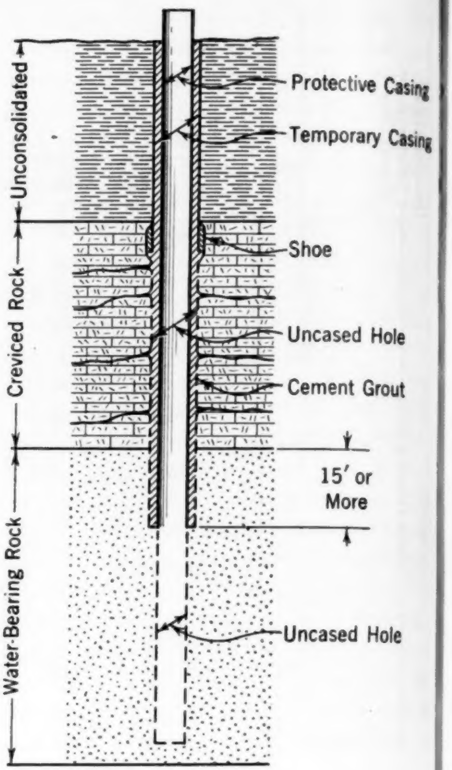
It is common practice to drive the casing into the rock without under-reaming and attempt to obtain a good seal by grouting. This is not good construction practice, however, because there is insufficient penetration of the casing into hard rock and, further, because there is no certainty of forcing the cement into the narrow annular space and thus obtaining a tight seal.

4.3.7—*Type 7—Consolidated Formation, Underlying Clay or Hardpan*

For non-caving formations, and particularly where protection against corrosion may be essential, the grouted



TYPE 8
CONSOLIDATED FORMATION

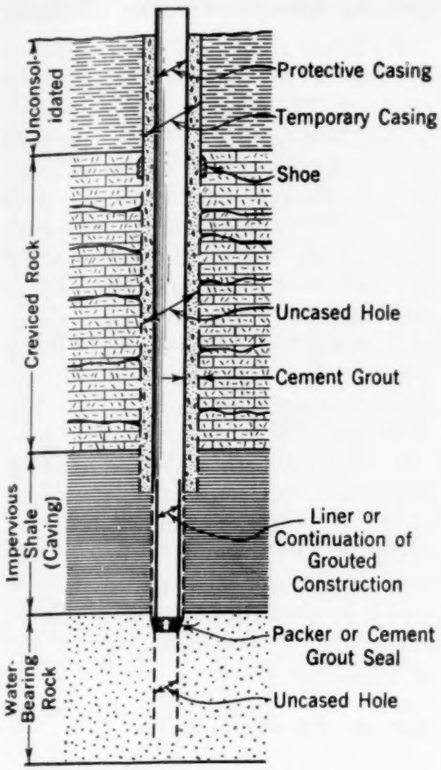


TYPE 9
CONSOLIDATED FORMATION

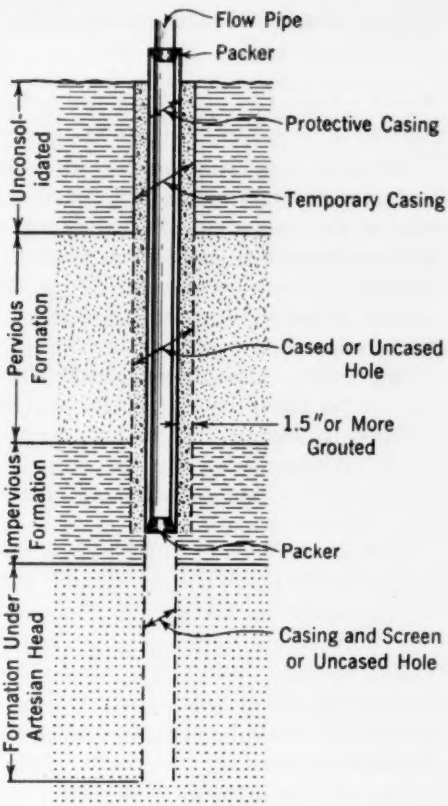
casing type of construction is recommended.

4.3.8—*Type 8—Consolidated Formation, Channelized, Creviced or Shattered Rock*

Formations that are channeled, creviced or fractured may yield unsafe water. They should be avoided as a source of supply, unless overlain with an adequate thickness of unconsolidated formations over an extensive area. Should sinkholes, quarries, outcrops or improperly constructed wells be located in or near the site, particularly if they are located in the line of flow of the water in the water-bearing formation toward the proposed well, the developed supply should receive adequate continuous treatment and the sanitary quality of the water should be checked regularly. Where there is an adequate cover of unconsolidated material and existing ungrouted wells tap only the upper portion of the formation, a measure of protection may be obtained if the supply is developed by extending watertight construction of the well to a depth greater than that of the deepest existing well of questionable construction. The watertight construction should extend to a point substantially below the lowest water level.



TYPE 10
CONSOLIDATED FORMATION



TYPE 11
ARTESIAN CONDITION

4.3.9—*Type 9—Consolidated Formation, Water-Bearing Rock Below Creviced Rock*

Where an adequate water supply of suitable quality can be obtained from a rock formation overlain by a creviced rock formation, the creviced formation should be completely cased off and watertight construction extended into the water-bearing rock formation.

4.3.10—*Type 10—Consolidated Formation, Impervious Formation Underlying Creviced Formation*

Where a formation known to be impervious and continuous over a large area underlies a creviced or contaminated water formation and overlies the water-bearing formation, termination of the protective casing in the top of the impervious formation is acceptable construction. Such protective casing should be surrounded with cement grout. If the impervious formation is of a caving nature, the installation of a liner through it and into the underlying stable formation will be necessary. The lower terminal of such liner should be adequately sealed or set in grout, or the full length of the liner should be surrounded with grout. To avoid the reduction in diameter necessitated by use of a liner, the grouted type of construction could be continued

through the impervious caving formation.

4.3.11—*Type 11—Artesian Conditions, Possibly Producing Flowing Wells*

When a well is projected into an artesian water formation, the construction of the well should be such that it will conserve the supply and head by preventing loss of water into overlying porous formations under less head or by leakage to the surface around the casing pipe. The construction also should be such that if a flow is developed it may be kept under control. Such artesian wells may be properly developed in either consolidated or unconsolidated formations.

In the construction of such wells the initial drilling operations should extend into, but not through, the impervious formation confining the water under artesian head. The protective casing and the annular space cement-grout seal should be installed and given ample time to set. The drilling operations into the artesian strata are then continued with or without casing protection. Where the nature of the impervious confining bed is such that erosion by the flowing water will occur, a casing extending into the artesian aquifer is essential.

Flow control devices may consist of valved pipe connections, watertight pump connections or receiving reservoirs, set at an altitude corresponding to that of the artesian head. Valving arrangements should be automatic if manual control to prevent waste of water is not practical. The life of an artesian well, particularly if the water is corrosive, may be prolonged substantially by the installation of a replaceable eduction or flow pipe, properly sealed with packers at the top and bottom of the casing.

Sec. A1-4.4—Construction Methods

Wells are commonly constructed by the use of any one of the following five methods—digging, jetting, boring, driving and drilling. These specifications deal largely with drilled wells, as they are the type most commonly used for public water supply purposes. Most drilled wells are constructed by the cable tool, "standard" or percussion method. The hydraulic rotary method has been widely used in recent years. There are many claimed and real advantages for each of these two methods. It is recommended, however, that the method of drilling be left to the well contractor unless the writer of the specifications knows from experience, or determines from the advice of disinterested parties experienced in well construction in the locality, that a particular method will give superior results.

Sec. A1-4.5—Test Wells

Test wells or test holes do not differ materially from permanent wells or holes except that they are usually smaller, may have lighter casings and are generally not grouted. As a rule, no special care is taken in their construction to seal out undesirable water or to get the wells straight. Test holes or test wells are not used to any considerable extent in consolidated formations because of the expense of drilling and because exploratory work is not generally required except where the general geology of the region is not known. (Test wells can sometimes be converted to permanent wells by reaming to a larger diameter.)

Test wells are used extensively in connection with wells in unconsolidated formations. They are used to locate sites for wells and to determine whether

a site will yield the required quantity of water. Test wells are valuable for obtaining information to determine the proper depth of the permanent wells, the best location for their screened sections, size of slots, etc. (Particularly where the hydraulic rotary method is used, test holes are frequently converted to permanent wells by reaming or under-reaming.) The interpretation of results obtained from test holes or test wells requires experience and a thorough knowledge of well drilling procedures and principles.

As a test well may afford a means for surface water or water of undesirable chemical quality to enter a formation that yields potable water, care should be exercised in sealing with puddled clay or cement grout all test wells as soon as they have served their functions in connection with the exploratory work.

Sec. A1-4.6—Developing

Wells in unconsolidated formations are frequently developed by the use of any one or a combination of several methods, including over-pumping, intermittent pumping, surging with a plunger, surging with compressed air and backwashing with water. Wells in consolidated formations are generally not developed but there is evidence to the effect that, in at least a few formations, development does increase the yield. The comments given below relate to unconsolidated formations only.

It is hazardous to specify the exact method that should be followed in developing a well unless the writer of the specifications is an expert in the field of well drilling and knows by experience how the particular formation reacts to development. The yield of the well may be lost or greatly reduced by over-development and yet, on the other hand, many wells will be "sand pumpers" or will yield only a fraction of their possible maximum, if they are not adequately developed. Methods of development and their application differ with the water-bearing formations, with the companies drilling the well and with individual drillers.

It is not sufficient merely to state in the specifications that the well should be developed, because running a bailer up and down in the well a few times will provide some agitation and could be called developing. If no particular method is to be described a general clause such as the following is suggested:

> The contractor shall furnish all necessary pumps, compressors, plungers or other needed equipment and shall develop the well by such approved methods as shall be necessary to give the maximum yield of water per foot of drawdown and extract from the water-bearing formation the maximum practical quantity of such sands as may, during the life of the well, be drawn through the screen when the well is pumped under maximum conditions of drawdown.

Sec. A1-4.7—Gravel Packing

Methods of gravel packing, like methods of developing, are not for the novice to specify. Gravel-packed wells are also known as gravel filter or gravel wall wells. Gravel packing is the process by which selected gravel is placed between the outside of the well screen and the face of the undisturbed water-bearing formation. It is especially useful in the development of water from formations composed of fine material of uniform grain size. Either during or after the well is gravel packed the usual development processes are carried on to remove such fine material as may be unstable and to

stabilize the inserted gravel. During the development of a well which is finished with a screen having properly selected slot openings and which derives water from an aquifer consisting of coarse and fine grained material, natural rearrangement of the individual grains of material comprising the formation occurs. The coarse particles tend to be arranged around the outside face of the screen, whereas the finer particles are removed in the section adjacent to the screen. This process is sometimes designated as "natural gravel packing."

The following represents an example of a specification for gravel packing a well constructed by the casing method with the use of a cable tool rig:

After the casing has been installed for the full depth of the well and the screen has been placed in its proper position, a wall of gravel shall be placed around the screen and also in the annular space between the inner casing and the outer casing from the bottom of the screen to a point 20 ft. below the level of the ground. Gravel used for this purpose shall be clean, washed gravel composed of well-rounded particles. The size of the gravel shall be carefully selected with reference to the character of the water-bearing formation to be packed.

Gravel to be placed in the section between the bottom of the screen and the bottom of the outer casing in its final position shall be placed in 2-ft. layers as the casing is raised.

A specification for graveling a well where the rotary method is used follows:

After the inner casing is in position and before the gravel wall is placed, wash lines shall be lowered into the annular space between the inner and outer casings of the well. These wash lines shall be provided with suitable nozzles and provision shall be made for supplying an adequate quantity of clear water under pressure of not less than 75 psi. in excess of the static pressure at the bottom of the well. A pump of sufficient capacity to remove the quantity of water added during washing operations shall also be provided. Beginning at the bottom of the well, all mud, sand and other fine material shall be thoroughly washed from the sides of the well and shall be continuously removed. The wash lines shall be withdrawn as gravel of suitable size is placed. Sufficient labor and equipment shall be provided so that the washing of the walls of the hole, the withdrawing of the material thus washed off the walls and the graveling process will be continuous.

Normally, either the cable tool or hydraulic rotary method may be used for a gravel-packed well and therefore the specifications may be left open.

Section A1-5—Well Casings

(See Section 1-2 in Specifications)

Sec. A1-5.1—General

This section sets forth the purposes of casings and the materials used. Different casing requirements for various types of construction and sub-surface formations are discussed in Sec. A1-4, "Description of Work."

Sec. A1-5.2—Purpose of Casings

Well casings and liners have the dual purpose of sealing out contaminated and other undesirable water and of maintaining the opening from the surface to the water-bearing formations. To be wholly effective the casings and

liners should be constructed of suitable materials and be so installed as to accomplish their intended purpose.

Sec. A1-5.3—Casing Materials

5.3.1—*Materials in Common Use*

The materials in most common use for well casings or liners are wrought iron, alloyed or unalloyed steel and ingot iron. The use of cast iron for this purpose is increasing. Cement-lined and enamel-lined pipe of the above materials is available and is suitable for some wells.

In some instances wells have been cased with copper pipe and others with asbestos-cement pipe. Copper steel and copper-nickel steel have not been used extensively and it is doubtful if these materials will outlast unalloyed steel. Other alloys, such as stainless steel, are suitable but prohibitive in cost. Ingot-iron pipe is frequently used in constructing gravel wall or other wells of large diameter. (The reader is referred to Bureau of Standards Research Papers Nos. 95, 329, 359, 638 and Technical Paper No. 368 for Reports on Investigations of the Effect of Soils on Metals.) Concrete casings and screens have been used frequently with success.

5.3.1.1—*Copper Pipe.* Seamless copper pipe is listed by manufacturers for diameters up to 8 in. Data with respect to such pipe and larger sizes should be obtained from the manufacturers or jobbers.

5.3.1.2—*Ingot-Iron Pipe.* Ingot-iron pipe is fabricated up to large diameters. It is usually produced with riveted seams and joints.

5.3.1.3—*Asbestos-Cement Pipe.* This material is suitable for protective well casings. Due to the slip-joint type of construction its use is limited to short inserted settings unless special arrangements are made to suspend the pipe from its bottom.

5.3.1.4—*Pipe Linings.* Pipes lined with cement, porcelain and vitreous enamels, bitumastic enamel and rubber are manufactured for corrosion protection. In the use and handling of lined pipe it is necessary to protect the linings against injury during drilling operations and installation of pumping equipment. Use of soft linings is not recommended for pipes used as well casings.

5.3.2—*Points To Be Considered*

In the selection of the type of pipe it is necessary to consider the strain to which the pipe will be subjected during installation and the corrosiveness of the water with which it comes in contact. Obviously, cast-iron pipe, copper pipe and pipe with a non-tenacious or shatterable lining should not be driven. These materials and linings, however, are known to be corrosion resistant and deserve consideration when the construction of the well is such that they may be set in place. Of the other materials, wrought-iron and steel pipes have given satisfactory service in many locations, wrought-iron being preferred occasionally for protection against corrosion.

Sec. A1-5.4—Weights of Steel and Wrought-Iron Casing Pipe

It is important that in drawing specifications the desired weights be stated, as there are many weights of steel and wrought-iron casing sold under various trade names and merely to call for a pipe having a certain nominal diameter is not sufficient.

Tables 1 and 2 present data on steel and wrought-iron pipe recom-

mended for use as permanent well casings. Lighter weight wrought-iron and steel pipe is suitable for temporary casings for some wells, and also for inserted casings and liners if approved by regulatory agencies. It is sometimes advantageous to use casing pipe of odd diameters and weights other than those listed in the following tables in order to achieve a minimum of reduction in the size of the hole.

Sec. A1-5.5—Casing Joints

For casings used for protection against contamination, the joints should be welded or made up with threaded couplings. Joints on temporary or construction casings may be riveted. Couplings providing for butt pipe joints are favored by many drillers but not by pipe manufacturers. Porcelain, vitreous enamel and rubber-lined pipe have flanged joints.

Sec. A1-5.6—Casing Strings

The string of pipe used as the protective casing in a well should be continuous with tight joints from its bottom terminal to a height above the

TABLE 1

Steel Pipe, Black or Galvanized *

Nominal Size, *in.*	Diameter, *in.*		Thickness, *in.*	Weight per Foot, *lb.*†	
	External	Internal		Plain Ends Calculated	Threads and Couplings Nominal‡
6 id.	6.625	6.065	0.280	18.97	19.45
8	8.625	7.981	0.322	28.55	29.35
10	10.750	10.020	0.365	40.48	41.85
12	12.750	12.000	0.375	49.56	51.15
14 od.	14.000	13.250	0.375	54.57	57.00
15	15.000	14.250	0.375	58.57	61.15
16	16.000	15.250	0.375	62.58	65.30
17	17.000	16.214	0.393	69.70	73.20
18	18.000	17.182	0.409	76.84	81.20
20	20.000	19.182	0.409	85.58	90.00
21	21.000	20.125	0.438	96.07	
22	22.000	21.125	0.438	100.75	
24	24.000	23.125	0.438	110.10	
26	26.000	25.125	0.438	119.44	
28	28.000	27.000	0.500	146.85	
30	30.000	29.000	0.500	157.53	
32	32.000	30.875	0.563	188.86	
34	34.000	32.875	0.563	200.87	
36	36.000	34.750	0.625	236.13	

* 6–20-in. dimensions and weights from API Specifications 5-L for Line Pipe: 22–28-in. dimensions and weights from A.W.W.A. Specifications 7A.4: 30-in. dimensions and weights from U.L. Specifications I-888: 21-, 32-, 34- and 36-in. dimensions and weights not derived from standards.

† Permissible variation in weight is 10 per cent above and 3.5 per cent below but the carload weight shall not be more than 1.75 per cent below nominal weight.

‡ Based on a length of 20 ft., including coupling. Threaded pipe has 8 threads per inch.

Note: Welded joints advocated for pipe larger than 20 in. in diameter; also for smaller diameter pipe, where applicable, to obtain clearance and maintain uniform grout thickness.

ground sufficient to assure adequate surface protection.

Sec. A1-5.7—Temporary Casings

In these specifications reference is made to "outer" casings. These may usually be considered as temporary units that could be withdrawn as a grout seal is placed. Under certain conditions such "outer" casing pipe may be lighter in weight than that specified in the tables. When the outer casing is considered of temporary nature or only as a needed construction item, the selection of the weight and type of pipe may be left to the discretion of the contractor. He should be held responsible, however, for satisfactory completion of the well to the dimensions provided for by the specifications.

It is suggested that where casings of the temporary type are required a clause similar to the following be inserted in Sec. 1-2 of the specifications:

The ....-in. od. outer casing, intended for construction purposes only, shall be of such weight and design as necessary to prevent entrance of sand and silt, to be reasonably watertight, and to permit its installation without distortion or rupture to the specified depth and dimension.

Sec. A1-5.8—Inserted Casings or Liners

This term is applied to casings and liners that are installed without driv-

TABLE 2

Wrought-Iron Pipe, Black or Galvanized *

Nominal Size, *in.*	Diameter, *in.*		Thickness, *in.*	Weight per Foot, *lb.*†	
	External	Internal		Plain Ends Calculated	Threads and Couplings Nominal‡
6 id.	6.625	6.053	0.286	18.97	19.45
8	8.625	7.967	0.329	28.55	29.35
10	10.750	10.005	0.372	40.48	41.85
12	12.750	11.985	0.382	49.56	51.15
14 od.	14.000	13.234	0.383	54.56	57.00
15	15.000	14.234	0.383	58.57	61.15
16	16.000	15.234	0.383	62.57	65.30
17	17.000	16.197	0.401	69.70	73.20
18	18.000	17.165	0.417	76.84	81.20
20	20.000	19.165	0.417	85.57	90.00
22	22.000	21.125	0.438	98.77	
24	24.000	23.125	0.438	107.96	
26	26.000	25.125	0.438	117.12	
28	28.000	27.000	0.500	143.99	
30	30.000	29.000	0.500	154.46	

* 6-12-in. dimensions from ASTM Specifications A72-39, weights from manufacturer's specifications for wrought-iron line pipe: 14-20-in. dimensions and weights from manufacturer's specifications for wrought-iron line pipe: 22-30-in. dimensions and weights from manufacturer's specifications for wrought-iron large od. pipe.

† Manufacturer's tolerance above or below nominal weight is 5 per cent for 6- to 20-in. pipe and 10 per cent for larger sizes.

‡ Based on a length of 20 ft., including coupling. Threaded pipe has 8 threads per inch.

Note: Welded joints advocated for pipe larger than 20 in. in diameter; also for smaller diameter pipe, where applicable, to obtain clearance and maintain uniform grout thickness.

ing, normally constituting the inner or main well casing, and the liners installed through caving formations or for sealing out water of poor chemical quality. Such pipe may be lighter than that indicated in the foregoing tables where structural strength or additional protection against corrosion is not required. It is, however, suggested that no casing pipe utilized for protection against contamination be less than $\frac{3}{8}$ in. in thickness, unless standard pipe is of lesser thickness or the casing is surrounded with 6 in. of concrete.

Sec. A1-5.9—Drive Shoes

The use of drive shoes for driven permanent casings is recommended. They may not be required for shallow settings of temporary casings in unconsolidated formations. The type and weight of the drive shoe may normally be left to the discretion of the contractor. Drive shoes are not required on inserted casing pipe and liner pipe.

Section A1-6—Well Screens

(See Section 1-*2.2* in Specifications)

Sec. A1-6.1—General

Wells deriving water from unconsolidated formations are generally equipped with well screens. The well screen allows water from the aquifer to enter the well while at the same time it supports the water-bearing formation and prevents the drillhole from collapsing. Usually the well screen performs the important function of preventing sand from entering the well.

The selection of a well screen is frequently a complicated matter demanding a highly specialized knowledge of well construction and operation. Unless the writer of the specifications has had experience in selecting screens or knows that a certain size and type of screen is commonly and successfully used in the particular aquifer from which the water is to be derived, it is advisable to consult a reliable screen manufacturer, well-drilling contractor or engineer experienced in this kind of work.

If water is to be obtained from a well tapping more than one aquifer, the screens required for the various water-bearing strata may require different sized openings, thereby necessitating a modification of the specifications.

For the purposes of these specifications it is assumed that, if a well derives its supply from rock, no screen is required. There are, however, unusual conditions which may make screens necessary.

Sec. A1-6.2—Diameter and Length

The exact diameter of the screen for a given size of casing will depend on the method of installation that is employed. The length of active screen must be determined in relation to the thickness of water-bearing strata, type of screen, size and spacing of openings, required well capacity and similar factors. For best results the screen should be designed to produce a minimum loss of head or drawdown between the water-bearing strata and the well. In many instances it is desirable not to specify the length in advance but to wait until adequate information is available regarding the

thickness and character of the water-bearing strata. In such cases the screen should be paid for on a cost-plus basis.

Sec. A1-6.3—Materials for Well Screens

Strike out the material or materials not desired. They are listed in the specifications in their approximate order of corrosion resistance.

The materials most commonly used for corrosive waters are Everdur metal, silicon bronze, Toncan iron and Armco iron. Some other materials give greater corrosion resistance but are higher in cost and their use is probably warranted only in cases where extremely corrosive conditions are anticipated.

The proper selection of the material for the screen is a matter of economics in which the chemical character of the water plays an important role. Lacking knowledge with which accurately to determine the proper material, a screen composed of an alloy having the approximate analysis of 96 per cent copper, silicon and manganese and known commercially as Everdur metal or silicon bronze will frequently be recommended by manufacturers.

As the selection of materials will depend directly upon the corrosiveness of the water, an intelligent selection can be made only if chemical characteristics of the material are known. Samples of water for analysis must be carefully secured by one experienced in such work in order to avoid loss of carbon dioxide and dissolved oxygen. If it is anticipated that acid treatment may be required to remove incrustation, the screen material must be capable of resisting the corrosive action of this treatment.

Sec. A1-6.4—Type

Strike out the types not desired.

Sec. A1-6.5—Openings

The size of screen openings should be expressed in thousandths of an inch. The number and type of slots or openings are dependent upon the type of screen selected and upon the area required to obtain sufficient screen capacity. The width of slot is best determined on the basis of a mechanical analysis of a sample of the water-bearing medium.

When a well screen is placed in an aquifer which is to be developed but where gravel is not to be added between the screen and the stratum, the size of slot is controlled by the effective size and the uniformity coefficient of the sand to be screened. The finer particles of sand will pass through the screen during development, leaving the coarser particles adjacent to and outside the screen. If the openings used are too small the yield of the well will be reduced by inadequate development and cementation may soon close the openings. If the openings used are too large, an excessive amount of development may be necessary and sometimes it is even impossible to clear the well of sand. Screen manufacturers usually maintain a screen selection service and will make mechanical analyses of samples and recommend the proper size opening.

When a well screen is surrounded by an artificial gravel wall the size of the openings is controlled by the size of gravel used and by the type of openings. The gravel should be quartz, carefully screened to the size or sizes best suited for the maximum development of water from the aquifer. Theoretically, the gravel size is controlled by

the size of the sand and the velocity of the water entering the gravel envelope at its outer circumference. In practice, ¼-in. gravel, carefully graded, is usually satisfactory for sands commonly encountered. The experience of reputable well drillers specializing in artificial gravel wall wells is the best guide to the selection of the proper size gravel.

Sec. A1-6.6—Fittings

6.6.1—*Bail Plug*

It is necessary to close the bottom of the screen with a plug or other device. The term "bail plug" includes not only the fitting known in the trade as a bail plug but all types of metal plugs used to seal the bottoms of well screens. If a plug having a bail for easy removal is required it should be so stated. Large-diameter screens are often closed with a plug of quick-setting neat cement, lowered into place with a bucket.

6.6.2—*Seals*

Many excellent types of patented seals and packers are available in addition to the standard lead ring. The lead ring, if used, should be fastened securely to the top of the screen and should be of sufficient thickness and length. The usual procedure is to lower the screen to its final position in the casing and expand the lead packer with a swedging tool. This type of seal is very nearly standard for single-cased wells up to 8 or 10 in. in diameter and has been used with success on larger sizes.

6.6.3—*Tail Pieces*

These are sometimes required to provide for adequate development of the lowest part of the screen. A length of 5 ft. is usually sufficient for this purpose.

6.6.4—*Extension Pieces*

These are used in artificial gravel wall wells where it is customary to extend the inner casing to which the screen is attached 50 to 100 ft. up into the next larger casing. The extension piece immediately above the screen need not be more than 5 ft. long, but it should be of the same material as the screen, to prevent electrolytic corrosion of the screen. The additional extension required should be considered as inner well casing and be of the same material as the casings.

6.6.5—*Blank Sections*

These are sometimes used where an otherwise satisfactory water-bearing stratum contains one or more lenses of soft, runny material. The blank section is set opposite the soft lens to reduce the disturbance caused by development at that point. The installation and development of a screen set with blank sections for this purpose are difficult and should be done only under expert guidance.

Section A1-7—Testing for Yield and Drawdown

(See Section 1-4 in Specifications)

Sec. A1-7.1—Purpose of Testing

It is customary to make preliminary tests for various reasons, such as to determine whether the well should be drilled deeper, whether it requires development and to secure water samples for analysis. A final test is almost always a necessity in order to ascertain

the well's capacity and to secure information so that permanent pumping equipment may be intelligently selected.

The following notes refer to blanks left in Secs. 1–4.2, 1–4.3 and 1–4.4 of the specifications.

Sec. A1–7.2—Maximum Capacity Test Pump

In most instances the maximum capacity of the test pump should be equal to the maximum quantity of water that it is anticipated the well will produce and not merely equal to the capacity of the pump that is planned for permanent use. For example, if 200 gpm. were desired and yet it was expected that the well might deliver as much as 500 gpm., the higher figure should be used so that the well's maximum capacity may be determined and made a matter of record for use in ordering future pumping equipment or in designing adjacent wells. It is frequently advisable to over-pump a well during the test run in order to determine the presence of sand.

Sec. A1–7.3—Maximum Pumping Head

The figure denoting the maximum pumping head should be the difference between the lowest anticipated pumping level and the ground surface at the well.

Sec. A1–7.4—Minimum Pumping Capacity

The minimum pumping capacity should also be stated and is frequently about 20 per cent of the maximum. One reason for requiring that the pump be capable of operating at different rates is so that, at the conclusion of the final test on the wells, the drawdown at different rates of discharge may be ascertained and the most economical pumping level selected. If a deep well turbine, or any type of pump driven by a gasoline engine, is used, it is generally a simple matter to vary the rate of discharge.

Sec. A1–7.5—Ability of Test Pump to Operate Continuously

The maximum period for which the test pump should be able to operate should be stated in the specifications, particularly if it is to be driven by a gasoline engine, as some engines of this type are not capable of prolonged continuous operation. It is recommended that the time, as stated in this paragraph, be at least 24 hours longer than the time stated in the specifications for the duration of the final test.

Sec. A1–7.6—Disposal of Water

In most cases the water pumped from the well can be discharged onto the surface of the ground immediately adjacent thereto. There are instances, however, where this should not be done and, if such is the case, the contractor should be so notified. An example of the necessity of disposing of the water is where its discharge near the well will cause damage to surrounding property or structures. Another example is where the well is shallow and only a limited depth of impervious material lies between the water-yielding stratum and the surface of the ground. Water should be conducted far enough away from this type of well so that it will not be re-circulated. The distance necessary will depend on local conditions.

Sec. A1–7.7—Duration of Test

The length of time for which the final test should run depends entirely on local conditions and no general rule can be stated here. Due to the uncer-

tainty at the time the specifications are prepared regarding the necessary or advantageous length of a test, it is recommended that *in this section* a figure be used that represents the best judgment of the minimum time of test and in Sec. A1–7.5 of the maximum time of test.

It is further recommended that, except in the case of wells contracted for on the guaranteed yield basis, the contractor be paid by the hour for testing. If, during the test, the well performs favorably, the period may be kept to the minimum with a consequent saving to the client. If the reverse is true, the test period can be extended and the contractor may be paid for his extra expense.

Sec. A1–7.8—Factors Influencing Duration of Test

7.8.1—*Local Experience*

Where wells have been operated nearby and in the same formation so that water-yielding qualities of similar wells are fairly well known, the period of test can be more limited than otherwise. An exception to this, however, is where it is desirable to note the effect of the new well on adjacent existing wells.

7.8.2—*Intermittent Pumping*

If it is anticipated that the well will be pumped for only a limited period each day with the result that the ground water level will be able to rise again to its normal position, the period of test may be shorter than it would be if the well were to be operated constantly.

7.8.3—*Limited Draft*

If the capacity of the permanent pump to be placed in the well is to be much smaller than the demonstrated output of the well at the start of the test, the tendency is to cut the test period shorter than if it is desired to get every possible bit of yield from the well.

7.8.4—*Other Supplies*

If the well is to be the sole source of supply the tendency is to extend the period of test longer than it would be if other sources were available that could be used during a period when the yield of the well might fall off.

7.8.5—*Investment in Auxiliary Equipment*

If a large sum of money is to be spent for auxiliary or other equipment, the utility of which will depend on the quantity of water to be secured from the well (for example, pump houses, purification equipment, discharge lines, etc.), the period of test should be more extended than in a case where failure of the supply would affect only the amount of money invested in the well itself.

7.8.6—*Season of Year*

The tendency is to lengthen the period of test during wet seasons and to shorten it in dry ones where the areas of water-bearing formations or tributary watersheds are small.

7.8.7—*Method of Payment*

The method of paying for the well also affects the period of test. If the well is purchased on the guaranteed yield basis and the contractor is to be paid immediately upon conclusion of the final test, the test period should be longer than otherwise because the yield is the basis for payment and, consequently, any falling off affects the cost of the well to the owner.

This statement holds true to a certain extent even if the yield is guaran-

teed for a considerable period of time after the final test. Generally the pump houses, pipelines, electrical work, etc., are furnished by the owner and there is considerable loss not covered by the guarantee if the supply fails later on. Furthermore, the well will probably be operated at less than the guaranteed capacity during the period covered by the guarantee.

7.8.8—Water Level

The engineer should use extreme care and judgment in directing and interpreting the test. The yield at the start of the test is not particularly important if the water level is still dropping. The important part of the test is the yield after the water level in the well has become practically stationary. It is recommended that in most cases the test pump be run until the water level in the well is stabilized while pumping at a constant rate and that after this point has been reached the test be continued for several hours to make sure that conditions do not change. Observations should also be made of returning water levels after pumping has ceased. A rapid return to the original level is a good sign.

Sec. A1-7.9—Maximum Drawdown

If a well is purchased on the guaranteed yield basis, it is recommended that after Sec. 1-4.4 of the specifications the following be added:

Sec. 1-4.5—Maximum Drawdown

The maximum drawdown during the test shall be at least 5 ft. above the highest perforation on the screen. The yield of the well to be used as a basis of payment and as determined hereunder shall be the average output in gallons per minute during the final 24 hours of the test, provided, however, that during such period rates of discharge and the water level in the well shall have remained substantially in equilibrium and that the discharge rate for the preceding period of the test shall have been at least as great.

If the proposed wells are deep and a drawdown to within 5 ft. of the top of the screen would entail pumping against a greater head than economically feasible, the maximum allowable drawdown should be stated in terms of distance below the surface.

Section A1-8—Grouting and Sealing

(See Section 1-5 in Specifications; see also Section A1-4 in Appendix)

Sec. A1-8.1—General

This section explains the purpose of grouting or sealing wells, materials used and suitable methods of placing the grout.

Sec. A1-8.2—Reasons for Grouting and Sealing

Grouting and sealing of water wells is practiced to protect the supply against pollution, to increase the life of the well by protecting the casing pipe against exterior corrosion, to seal out water of an unsatisfactory chemical quality and to stabilize soil or rock formations of a caving nature.

8.2.1—Pollution Prevention — Depth of Seal

In the construction of wells there is normally, and sometimes purposely, produced an annular space surrounding the casing, which, unless sealed, provides a definite channel for downward movement of water. In caving formations, such as sand, the opening

would tend to be self-sealing. In the more stable formations, such as clay, shale and rock, some method of sealing the opening must be provided to prevent entrance of contaminated water directly from the surface or from creviced rock formations connected with the surface.

Sealing of the annular space in itself, however, is not a panacea for pollution. In every well the casing and seal must extend to such height and depth as will prevent contaminated water from entering from the surface or from the soil and rock strata through breaks in the natural protective formations. The depth required for protection depends upon the character of the formation, whether porous or impervious, fine or coarse-grained, and upon the depth and proximity of polluting sources, such as sinkholes, sewage disposal units, abandoned or poorly-constructed wells, mine workings, outcrops, etc.

Extension of well casing and sealing of the annular space are particularly important in creviced rock formations which have connection with the ground surface. Unless the annular space is sealed, a direct channel will exist between crevices in the upper part of the formation, which may contain grossly contaminated water, and the point of intake at the lower terminal of the casing pipe. In creviced rock formations considerable protection for the supply will be attained by casing and sealing the annular space to a depth of from 15 to 20 ft. below the lowest pumping level.

8.2.2—*Corrosion Protection—Thickness of Seal*

Protection of the exterior of the casing pipe against corrosion is provided by encasing it in cement grout. Mechanically, protection is obtained simply by excluding water from the face of the pipe. The degree of protection is dependent upon the thickness and density of the grout and upon the uniformity of the seal throughout its depth. A minimum thickness of $1\frac{1}{2}$ in. is recommended for wells for public water works systems, a greater thickness being desirable where severe corrosive conditions are known to exist.

8.2.3—*Sealing Unsatisfactory Water Horizons*

When formations located below the depth of the protective casing are known to yield water of an unsatisfactory chemical quality, such formations may be sealed off with liners, which, to be wholly effective, should be set in grout at least $\frac{1}{2}$ in. in thickness for the entire length. The use of packers at the ends of the liners should not be relied on for such seals because of possible faulty installations and the travel of water through porous formations around the packers. Pressure cement grouting, such as is practiced in oil well construction, could also be utilized to seal out undesirable water-bearing horizons.

8.2.4—*Stabilizing Formations of a Caving Nature*

When a casing is extended to or into a consolidated formation lying below an unconsolidated formation, the only means of preventing sand or silt from entering the well at the end of the casing is the seal formed between the edge of the drive shoe and the rock. Frequently such seal proves ineffective due to spalling of the rock or the existence of vertical crevices. To guard against failure of the well from such cause, an annular space for grouting should be provided or the lower termi-

nal of the casing should be set in cement grout.

Formations of a caving nature are sometimes located between two water-bearing horizons in consolidated formations. To protect the well, the caving formations should be stabilized by installation of a liner pipe. Although a packer at the lower terminal of the liner may prove satisfactory, greater assurance of adequate construction is provided by sealing the annular space with cement grout. Pressure cement grouting may also be utilized for stabilization of caving formations, particularly if they are of a porous nature.

Sec. A1–8.3—Materials for Grouting and Sealing

Materials used for sealing of wells should be of a character that will facilitate proper placement and thereafter asume a permanent and durable form. Normally, Portland cement grout will meet these requirements. Occasionally, however, the use of quick-setting cement will facilitate the well construction project, in which case it should be specified in Sec. 1–5.1. Under certain conditions, other materials may be desirable to accelerate or retard the time of setting, to lubricate the grout mixtures and to provide roughage for sealing of large crevices. In some instances, where large crevices are encountered, the use of a tight liner to minimize loss of grout may be essential. Cement-sand mixtures may also be used to reduce shrinkage and impart greater structural strength. One or two parts of sand to one part of cement and not more than 5½ gal. of water per cu.ft. of cement will provide suitable encasement material. Sand, however, should not be used in conjunction with roughage or lubricating materials such as "Jellflake," "Cellulose flakes," "Aqua Jell" or similar products.

Sec. A1–8.4—Grouting of Annular Space Surrounding Protective Casing

8.4.1—*Application in One Operation From Bottom Up*

To assure that the grout will provide a satisfactory seal it is necessary that it be applied in one continuous operation and be entirely placed before the occurrence of the initial set. It is also essential that the grout always be introduced at the bottom of the space to be grouted to avoid segregation of materials, inclusion of foreign materials or bridging of the grout mixture. Flushing of an open annular space with water before commencing grouting operations is a desirable precautionary measure to assure that the space is open and to provide for removal of foreign material.

8.4.2—*Various Methods Used*

The grout may be forced into the space to be grouted by suitable pumps or by air or water pressure. In some instances, placement by gravity or by means of dump bailers is also practical and satisfactory. The method used should be optional with the contractor provided there is no conflict with requirements of the specifications or with those indicated above for good construction practice.

8.4.2.1—*Grout Pipe Outside Casing.* If the annular space is of sufficient size to accommodate a grout pipe of such diameter as is necessary to complete operations in the time available, use of such pipe is satisfactory and perhaps the most fool-proof method of grouting. The pipe should extend to the bottom of the annular space ini-

tially and should remain submerged in grout during the entire time that grout is being placed. The pipe may be left in place or it may be gradually removed. In the event of interruption in the grouting operations, the bottom of the pipe should be raised above the grout level and should not be re-submerged until all air and water have been displaced from the grout pipe. The grout may be pumped into the pipe or applied continuously by gravity, although this method of placing grout is not advocated for depths in excess of 100 ft. or where the grout level cannot be readily determined by sampling or by displacement calculations. A minimum width of $1\frac{1}{2}$ in. is necessary to accommodate a $\frac{3}{4}$-in. coupled minimum-size grout pipe.

8.4.2.2—*Grout Pipe Inside Casing.* A second method of applying grout is by means of a pipe installed within the casing. The drillhole is plugged below the bottom of the casing or the grouting operation is conducted when the drillhole has been completed to the depth at which the casing is to terminate. A suitable packer connection, permitting removal of the grout pipe and preventing grout leakage into the interior of the casing pipe, is provided at the bottom of the casing. The casing is suspended slightly above point of bearing, and the grout is forced upward through the annular space by means of pumps or pneumatic pressure arrangements. When the annular space has been filled to the overflow point the grout pipe is disconnected and pulled out through the casing pipe. The casing may be held in place or lowered to the point of bearing. In deep settings the casing pipe should be kept full of water. After 72 hours or more, work on the well may be resumed by drilling out the grout pipe packer connection and plug.

When the well is drilled by the rotary method the grout may be forced into the annular space in a manner similar to that described above, except that the grout is applied through the hollow drill stem.

8.4.2.3—*Halliburton Method.* A third method of grouting is that employed by the Halliburton Oil Well Cementing Co. who hold certain patents thereon. With this method the grout is applied through the casing pipe, being preceded and succeeded by a "spacer" or "piston plug." In brief, the first plug is inserted and the casing capped; a measured volume of water is pumped into casing until the second plug reaches the end thereof. The first plug drops into the drillhole below the casing, which is suspended sufficiently to provide clearance, while the grout moves upward into the annular space. Neat cement grout is normally used for this method.

Sec. A1–8.5—Grouting of Annular Space Surrounding Liner Pipe

Liners installed in a well to seal out water of unsatisfactory quality or to stabilize caving formations can be successfully grouted in place. Since the grouting arrangements are complicated, it is suggested that the method of grouting of liners be outlined in detail by the contractor for the approval of the engineer.

Sec. A1–8.6—Pressure Cementing

Drillable liner pipe and packer arrangements, by means of which formations can be cemented under pressure

without permanently reducing the size of the drillhole, have been developed for the oil well industry. This method may be of some value in the development of water wells, particularly in those of considerable depth. Details thereon should be obtained from oil well contractors.

Section A1-9—Plumbness and Alignment

(See Section 1-6 in Specifications)

Sec. A1-9.1—Desirability of Plumbness and Alignment

If a turbine well pump is to be installed in a well, the well should be true to line from its top to a point just below the maximum depth at which it is proposed to set the pump. Plumbness is desirable although not nearly as important. Most manufacturers state that their pumps will operate satisfactorily when considerably inclined from the horizontal. A well out of alignment and containing kinks, bends or corkscrews should be rejected because such deviations cause severe wear on the pump shaft, bearings and discharge casing and, in a severe case, might make it impossible to get a pump in or out.

If an air lift or a suction pump is used for pumping, alignment is not important and the same claim has been advanced for the submersible type of pump. It is suggested, however, that even if it is intended to install a type of pumping equipment that will function satisfactorily in a well out of line, the requirements of these specifications be enforced. Except in very unusual cases, a reasonable amount of care on the contractor's part is all that is necessary to have the well straight and plumb and there exists the chance that before the useful life of the well has ended it may become desirable to use a turbine well pump.

Sec. A1-9.2—Recommended Method of Testing

The recommended method to be employed in testing a well for plumbness and alignment is described in Sec. 1-6.2 of the specifications. This method may be readily employed while the well rig or derrick is on the job. In making this test great care should be exercised to place the pulley supporting the line holding the section of pipe or dummy used as a plumb, so that at the start of the test it will be exactly centered in the casing. As the plumb is lowered into the well, measurements should be taken to determine the distance between the top of the plumb and the top of the casing and also to determine the horizontal deflection of the line at the top of the casing. To determine the amount of deflection of the well at the top of the lowered plumb, it is necessary to divide the horizontal deflection at the top of the well casing by the distance between the top of the casing and the point of suspension and multiply by the distance between the point of suspension and the top of the plumb. Readings should be made on two planes at right angles to each other in order to determine in which directions the well is off line or out of plumb.

Sec. A1-9.3—Permissible Deviations

Suggested maximum permissible deviations are contained in the speci-

fications. However, if the well as tested does not conform to the specifications, the contractor may be given a little more leeway as far as plumbness only is concerned, provided that, in the opinion of the engineer, the contractor has used due care and the defect is due to circumstances beyond the contractor's control, and, further, that the utility of the completed well is not materially affected. It sometimes happens that a boulder or inclined seam will throw the casing or hole out of plumb but not seriously out of line and occasionally remedial measures would be so expensive as to work a hardship on the contractor.

Sec. A1-9.4—Other Methods of Testing

After the well rig has been removed from the job a test for plumbness and alignment can be made with a small plumb and a tripod as described in Sec. E of the Standards of the Hydraulic Institute. This method is not as good as that called for in these specifications, however, for several reasons. The $\frac{1}{4}$-in. clearance of the small plumb does not allow for minor obstructions in the well. If the plumb is made short and with greater clearances it may tilt and throw the reading off. If it is made too light it will not hold the line tight and if too heavy may cause the cord to break. More important, if the readings are not carefully taken, the plumb may slip around a small section that is out of line without the deflection being detected.

Specifications have been written relating the desired straightness of the well to the size of turbine pump to be installed and to a test with a plumb having the pump's diameter. Difficulties with this method are that it is not always possible to determine even upon completion of the well just what size pump is to be used. Furthermore, leaving the pump size and hence the plumb size indefinite affords the well driller an opportunity to claim that the required quantity of water could be pumped with a turbine of smaller diameter, whereas the owner, in order to obtain increased operating efficiency, might prefer a larger pump.

Section A1-10—Disinfection

(See Section 1-7 in Specifications)

Sec. A1-10.1—General

This section sets forth the desirability of disinfecting wells, the time for such disinfecting and the methods and chlorine concentrations to be used.

Sec. A1-10.2—Desirability of Disinfection

In the construction of a well the drillhole is subject to contamination from the surface and from undesirable water horizons through which the well may be installed. Contamination is also introduced through handling of tools and casings and, in the case of wells drilled by the rotary method, through exposure of the drilling mud to atmospheric and surface pollution. A part of the contamination so introduced is carried into the water-bearing formations. Although pumping will normally remove such contamination, the production of safe water can be more quickly attained by disinfection of the well.

Sec. A1-10.3—Time of Disinfection

Normally, the time that a well should be disinfected is when construction is considered complete and the well is to be tested for yield. It should, however, be disinfected preceding the collection of any samples for determination of bacteriological quality. It is also desirable to disinfect the well after a permanent pump has been installed or when a pump is replaced after repairs.

Sec. A1-10.4—Methods of Disinfection

The first requirement for effective disinfection of a well is that the interior thereof be cleaned as covered in Sec. 1-7.1 of the specifications. The specifications prescribe that the method of disinfecting the well be left to the decision of the engineer, as it is realized that the varying conditions encountered will make it necessary to vary the methods used. In any disinfection procedure, however, the concentration of chlorine in the well or in water applied to the well should be at least 50 ppm. This amount is considered the standard concentration for the purposes of these specifications.

10.4.1—*Disinfection of Non-flowing Wells*

Method A—Where practical the chlorine solution of standard concentration used to disinfect the well should be prepared on the surface in containers having a volume equal to at least twice the volume of water contained in the well. This prepared solution should then be rapidly discharged into the well, care being taken to flush the walls of the well above the water level.

Method B—In lieu of the preparation of the solution of standard concentration in containers, a stock chlorine solution of 15,000 ppm. could be added to a continuous flow of water into the well to provide the standard chlorine concentration. Either of the above methods will carry the chlorinated water into the voids of the water-bearing formation and should provide effective treatment if the chlorinated water is applied rapidly enough to reach all formations penetrated by the well or is introduced at different levels in the well.

Method C—Should the above methods not be practical, a stock solution may be added to the well, preferably at different levels, to provide the standard concentration in the water contained in the well. The well should then be agitated with a bit or bailer in order to spread the chlorine solution throughout the water.

Method D—In lieu of using liquid chlorine solutions, a perforated pipe container capped at both ends, containing a granular chlorine compound, HTH or Perchloron, may be moved up and down in the well by means of a weighted cable. The amount of compound applied should be such as to provide the standard concentration.

10.4.2—*Disinfection of Artesian Wells*

For a flowing well discharging at the surface, it is probable that no disinfection will be required. This should be checked by bacteriological analysis as soon as possible but preferably not until 24 hours after completion of construction. Should the well prove unsafe, a stock chlorine solution should be applied for a period of 1 hour so as to provide the standard concentration in the flowing water, the point of application to be at or below the horizon producing the artesian condition.

Application of chlorine by means of solution from a pipe container, as described for non-flowing wells, may also be used for disinfecting artesian wells.

10.4.3—*Disinfection of Equipment and Material Used in Well*

If the well is disinfected prior to the insertion of the test pump, it is recommended that all exterior parts of the test pump coming in contact with the water should be thoroughly cleaned, wetted and dusted with a powdered chlorine compound. It is also recommended that, if possible, at the start of the operation of the pump, the pump discharge be so regulated that some of the chlorinated water may be returned to the well. In the case of a test pump, the pump can be installed sufficiently above the casing to permit this procedure and with a permanent pump the solution may be applied through the vent or air line opening in the pump base.

Sec. A1-10.5—Chlorine Solution

A stock solution of chlorine may be prepared by dissolving fresh chlorinated lime, HTH, Perchloron or other chlorine compounds in water in the proportion of 4 oz. of *available* chlorine to 2 gal. of water. This has a chlorine concentration of 15,000 ppm. or 1.5 per cent by weight. To obtain an applied standard concentration of 50 ppm., 1 gal. of the stock solution should be used to treat 300 gal. of water.

The following tabulation shows the number of ounces of chlorine or chlorine compounds of a given available chlorine content (generally marked on the outside of the can or package) required to provide a concentration of 50 ppm. in 1,000 gal. of water.

Application, *ppm.*	Liquid Chlorine, *lb.*	Chlorine Compounds, *lb.* Available Chlorine, %			
		15	25	30	70
50	6.7	44.7	26.7	22.3	9.6

The number of pounds of liquid chlorine or chlorine compounds that are required for the effective disinfection of the well may be computed by the use of the foregoing table together with the following table showing the contents in gallons per foot of wells of various diameters:

Diameter, in.	*Gal./ft.*	*Diameter, in.*	*Gal./ft.*	*Diameter, in.*	*Gal./ft.*
4	0.65	15	9.18	27	29.74
6	1.47	16	10.44	30	36.72
8	2.61	18	13.22	36	52.88
10	4.08	20	16.32	42	71.97
12	5.88	22	19.75	48	94.00
14	8.00	24	23.50	60	148.88

Section A1-11—Protection of Quality of Water

(See Section 1-7 in Specifications)

Sec. A1-11.1—General

In the construction of wells the intention should be to produce a safe water. This aim can normally be realized if, in selecting the well site, due consideration is given to possible sources of contamination in surrounding areas and proper heed is paid to

casing the well as described in Sec. A1–5 and grouting and sealing the well as set forth in Sec. A1–8. Only when a single available water-bearing formation lies so near the surface that it is continually contaminated is production of a safe supply not feasible.

Sec. A1–11.2—Obligation of Contractor

When the location of the well and the type of construction have been designated to the contractor, he cannot and should not be held responsible if the developed supply is of unsatisfactory quality, provided he has followed all requirements. The contractor, however, should be held responsible for defects developed in the course of construction that tend to reduce the protection naturally available at the site. He should be required to maintain formations above the aquifer in their natural state and, in case of failure to do so, he should be made to provide corrective construction equal to, or better than, that naturally existing at the site.

Sec. A1–11.3—Care To Be Taken by Contractor

In the construction of the well, due precaution should be taken by the contractor to maintain the premises in a sanitary condition and to avoid, as much as practical, the entrance of contaminated water into safe water-bearing formations. Any water or materials used in actual construction operations should be reasonably free of contamination and, if their nature permits, should be adequately disinfected with chlorine before use. The slush pit should be constructed so that no material therefrom will enter the well, except mud re-used when construction is by the rotary method. In such cases the slush pit and mud return channels should be protected against contamination from surface water or other sources.

Section A1–12—Shooting or Blasting

Sec. A1–12.1—General

In consolidated formations where the specific capacity of a well is rather low and where the rock formations are hard, the quantity of water to be obtained from a well may sometimes be increased by shooting. Shooting a well consists of lowering a bomb containing an explosive into the well, the explosive being provided with a cap and a pair of wires leading up to the surface so that the cap can be discharged, thus setting off the shot. There are many factors to be borne in mind if this procedure is to be undertaken and some of the most important ones are listed below.

Sec. A1–12.2—Advice Concerning Size and Location of Shots

Shooting a well should not be undertaken except upon the advice of someone who has had experience in this procedure, as the location and size of shots are important if the best results are to be obtained. Extreme care should be exercised as to the amount of explosive to be used. Very often such a large quantity of material is loosened that it is almost impossible to bail it out, and holes have often been lost by being over-shot. Both high pressures and low temperatures tend to reduce the effectiveness of explosives. Therefore, a recommendation from the

company which furnishes the explosive, specifying the quantity required, is generally desirable. In the Middle West, shots of from 50 to 200 lb. of 80 per cent high-velocity gelatin are used in wells 16 in. in diameter or larger. Before blasting, state and local ordinances should be checked to determine whether the services of a licensed blaster are required.

Sec. A1–12.3—Type of Container

The bomb or container for the dynamite should be of cast-iron soil pipe or some iron or steel cylinder, sufficiently strong and tight to prevent water from coming in contact with the explosive. It should be as large in diameter as can conveniently be lowered into the hole because the water between the bomb and the side of the hole acts as a cushion and this cushion should be as thin as possible. In some cases, successful shots have been made by simply putting the dynamite in a canvas bag, but this is not recommended for depths of more than 500 ft.

Sec. A1–12.4—Cleansing of Well After Shooting

When a well is shot, a large amount of material is loosened and drops to the bottom of the hole. Some of the material, however, remains on ledges in the side walls. It is desirable, therefore, that a test pump be installed and the well pumped at a greater rate than is contemplated for the permanent pumping equipment. This pumping generally washes a portion of the sand and debris from the side walls into the hole where it can be bailed out.

The test pump should be installed and operated a sufficient number of times so that no sand remains in the hole after the last pumping. Between each run of the test pump, the hole should be completely bailed out. The well should not be considered completed until no sand drops into the hole after at least 4 hours of pumping. This procedure is important because it will tend to prevent the well from producing sand.

Sec. A1–12.5—Insertions in Specifications

If it is anticipated that shooting or blasting will be required there should be inserted in the specifications a descriptive paragraph under Sec. 1–3, "Description of Work," and a payment paragraph under Sec. 1–12, "Measurement and Compensation." Payment is frequently set by a bid price per 50- or 100-lb. shot and an additional price per hour for bailing out the hole. Prices should be solicited in the proposal form.